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INVESTIGATION AND EVALUATION OF HIGH STRENGTH STEELS IN HEAVY GAUGES FOR LARGE DIAMETER SOLID PROPELLANT ROCKET ENGINE CASES

ROCKET RESEARCH LABORATORIES
EDWARDS AIR FORCE BASE, CALIFORNIA

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PREPARED UNDER CONTRACT No. AF 04(611)8517
BY
EXCELCO DEVELOPMENTS, INC., SILVER CREEK, NEW YORK
AND
MELLON INSTITUTE, PITTSBURGH, PENNSYLVANIA

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FORWARD

Investigation and Evaluation of High Strength

Steels in Heavy Gauges for Large Diameter

Solid Propellant Rocket Engine Cases

Technical Documentary Report covering the period

from 30 July 1962 thru 31 January 1963

EXCELCO Project 3291

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ABSTRACT

This research program includes the examination of candidate high strength steels (AMS 6434, D6AC, and Maraging 18% Nickel Steel) to determine the best candidate steel for use in large diameter solid propellant booster cases. Included are mechanical and physical properties, fabrication techniques, and tentative specifications and procedures for construction by the rolled and welded method of construction.

Specific requirements are the examination of plate and forgings ~~3/8" to 2"~~ 3/8 in. to 2 in. thick to determine mechanical and physical properties of the candidate materials welded and unwelded. Further, fabrications processes examined are forming, welding, machining, drilling and tapping, sawing, burning, and heat treating.

The results indicate that 250 Ksi Maraging Nickel Steel appears to be the best candidate. This is based on the basis of mechanical strength, G_c values, weldability, and the ease with which this material can be aged to the strength levels required.

AMS 6434 appears to be the second best choice based primarily on its weldability as compared to D6AC.

Tungsten arc inert gas welding (TIG) appears to be the best welding technique at present. However, metal arc inert gas welding (MIG) is very close and has the advantage of being somewhat more economical on very large cases (260 in. diameter) due to a faster deposition rate.

This research indicates that the proper course to follow is in developing the MIG welding process and the plasma arc burning process to their fullest advantage on 250 Ksi Maraging 18% Nickel Steel, and to further develop mechanical and physical data to establish reliability on this material.

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1.0 INTRODUCTION

1.1 The purpose of this research program is to examine several candidate high strength steels in the form of plate and forgings in order to evaluate these steels and select the best candidate for use in the fabrication of large solid propellant rocket engine cases. The candidate steels selected are D6AC, AMS 6434, and Maraging 18% Nickel Steel. The evaluation is to be based on certain mechanical properties of welded and unwelded plate and forgings (namely, tensile properties, charpy impact, hardness, and fracture toughness). This evaluation is very important since up to this time the only high strength large rocket engine cases successfully fabricated and tested are 120" diameter segmented cases of AMS 6434 heat treated to a yield strength of 210 Ksi and a tensile strength of 250 Ksi.

1.2 Further the objective of this program in selecting the best candidate steel for use in large solid propellant rocket engine cases will be to evaluate welding techniques (TIG - Tungsten inert gas, MIG, Metal inert gas, and submerged arc). Various fabrication processes such as forming, welding, machining, and heat treat response will be evaluated. Plate materials approximately .5" to .75" thick and rolled ring forgings 2" thick including a 120" dia. ring shell assembly are to be used in the investigation. Tentative material specifications and welding procedures are to be developed.

2.0 MATERIAL AND PROCESSES INVOLVED IN PROGRAM

2.1 Experimental Steels and Weld Rod

AMS 6434 - .500 in plate to 1-1/2 in. thick ring forging.

ref. photographs Fig 1 and Fig 2.

Plate: Heat - 319494 - Allegheny Ludlum Steel Corp.

Forging: Heat - EV-2671 - Standard Steel Works

Weld Rod: Heat - W-22138 - Allegheny Ludlum Steel Corp.

AMS 6434 - .500 in. plate Heat 13736 - Sheffield Steel Corp.

D6AC - .375 in. plate - Heat 920783 - Lukens Steel Corp.

D6AC - .375 in. plate - Heat X0629203 - Allegheny Ludlum Steel Corp.

D6AC - .75 in. plate - Heat 3950816 - Republic Steel Corp.

D6AC - Weld Wire - Heat 061257 - Armetco

Maraging 18% Nickel Steel - 300 Ksi .360 in. plate -

Heat 23831 - Allegheny Ludlum Steel Corp.

Maraging 18% Nickel Steel - 200 KSi .400 in. plate -

Heat 23560 - Allegheny Ludlum Steel Corp.

Maraging 18% Nickel Steel - 250 Ksi .500 in. plate -

Heat X 13371 - U.S. Steel Corp.

Maraging 18% Nickel Steel - 250 Ksi - .500 in. plate -

Heat 120D163 - Bethlehem Steel Corp.

Maraging 18% Nickel Steel - 200 Ksi - .500 in. plate -

Heat 4780-70979 - Lukens Steel Corp.

Maraging 18% Nickel Steel - 240 Ksi - .500 in. plate -

Heat 04524 - International Nickel Co.

Maraging 18% Nickel Steel - 250 Ksi, 6 in. x 2 in. x 12 in.

Forgings - Heat - not known - Standard Steel Works

Maraging 18% Nickel Steel - Weld Wire

250 Ksi - Heat 16524.33 - International Nickel Co.

300 Ksi - Heat 06919 - Armetco

250 Ksi - Heat W-24236 - Allegheny Ludlum

250 Ksi - Heat V-187 - Vanadium Alloys

2.2 Chemical Composition and Specimen Size

The chemical composition of weld wire is given in TABLE I and the plates and forgings in TABLE II.

TABLE III provides information relative to the sizes of plate samples procured, and the types and number of mechanical test specimens prepared.

The specimen layouts on seven plates or portions of the ring shell assembly are schematically indicated in Figures 3 thru 9. Figures 10, 11 and 12 show the specimen size and geometry of the parent plate and welded plate tensile specimens (Figure 10). Charpy V-notch impact test specimens (Figure 11) and fracture toughness specimens, G_c (Figure 12).

It may be noticed in the specimen layout drawings that full cognizance, wherever possible, has been given to rolling direction of plate material when determining mechanical properties and specimens for various weld zones in the welded plate specimens so as to uncover any strength limitations factors.

2.3 Heat Treatment

AMS 6434 was preheated at 900° F.

Heat in neutral salt bath to 1650° F. $\pm$ 25° F.

Hold one hour

Quench into salt at 400° F.

Hold 10 minutes

Remove and cool to 80° F.

Various samples were tempered for 4 hours at each of the following temperatures: 450° F, 525° F, 600° F, 700° F, and 800° F.

D6AC was astenitized at 1625° F for 30 to 45 minutes in neutral salt. Oil quench at 140° F. Tempered at various temperatures of 600° F through 1100° F.

Maraging 18% Nickel steel was all received in the solution annealed condition. Various treatments were used as follows:

a. Welded and unwelded plates aged at 850° F, 900° F, 925° F, and 1000° F for periods of 3 and 4 hours.

b. Plates aged at 925° F for 3 hours then welded. Weld area locally aged at 925° F for 3 hours. See Table IV, for results.

2.4 Fabrication and Machining Processes

All materials were subjected to various processes as follows:

Welding - MIG and TIG

Drilling and tapping - annealed and hardened

Milling - Annealed and hardened

Single point tool cutting - Lathe, boring mill, planer, (annealed and hardened)

Plasma arc cutting - annealed

Sawing - annealed and hardened

Forming - annealed

3.0 Experimental Results

3.1 Parent Metal Properties

3.1.1 AMS 6434

An evaluation of mechanical properties of AMS 6434 plate material has been conducted for specimens hardened and tempered in the range 400° F through 800° F. The results of this study have been recorded in Table V and plotted in Figure 13. The inconsistency in the curves Fig. 13 at 600° F tempering temperature are based on one test only and probably are not valid. However, the general pattern indicates a drop off of tensile properties above 700° F. with an apparent gain in elongation and reduction of area. The curves in general indicate that tempering should be done at either below 500° F or above 700° F to avoid the lower elongation and reduction of area range.

Mechanical property determinations were made on round, unnotched, and notched tensile test specimens of AMS 6434 and the values obtained are reported in Table VI. Also given in this table are fracture toughness test results for two .500 in. thick specimens of AMS 6434, quenched and tempered at 450° F and 800° F. These results substantiate the statement above that tempering should be done below 500° F or above 700° F.

Data of charpy impact tests conducted on AMS 6434 ring-shell assembly are provided in Table VII.

3.1.2 D6AC

Data of a study of D6AC plate material mechanical properties as a function of tempering in the range of 600° F through 1100° F are given in Table VIII and have also been graphically presented in Figure 14.

Charpy impact test data developed for specimens taken in the direction transverse to the rolling direction from Heat 3950816, quenched and tempered at 1000° F are provided in Table IX.

Fracture toughness test data obtained for D6AC plate are provided in a latter section along with those for welded plates.

Results of tension tests conducted on round, unnotched, and notched tensile specimens are included in Table X.

3.1.3 Maraging 18% Nickel Steel

The results of tensile tests conducted on flat plate specimens of various maraging steel compositions are given in Table XII. Data of a study of the effect of aging temperature upon various properties of a 200 Ksi maraging steel plate determined by tension test are provided in Table XII and also graphically presented in Figure 15 and 16.

Charpy impact test data obtained for plate material from various Maraging steel heats are provided in Table XIII. The fracture appearance in tension test and broken charpy specimens are shown in Figures 17, 18 and 19.

Listed in Table XIV are fracture toughness test results obtained for maraging steel plate specimens of various thickness. The fracture appearance in these specimens is depicted in Figures 20 and 21.

3.2 Welding and Plasma Arc Burning.

3.2.1 AMS 6434 Welded data.

A typical weld procedure sheet for the TIG process is shown in Figure 22. Tensile test results for Welded AMS 6434 plate specimens are given in Table XV and plotted graphically in Figure 23. This data is taken at various tempering temperatures from 400° F thru 800° F. Charpy impact data for welded AMS 6434 specimens taken from the ring shell assembly Figures 1 and 2 are provided in Table XVI.

Figures 24 and 25 are plots of the yield stress and tensile stress for welded AMS 6434 sheet and plate material from .08" thick to .625" thick. Data is compiled from many tests covering a five year period and are given to show that yield strength and tensile strength of this material appears to remain relatively constant thru a fairly large range of thickness.

Fracture toughness test results of welded AMS are given in Table XX.

A metallographic study of welded AMS 6434 is provided in Figures 32 thru 39 for material quenched and tempered at various temperatures from 400° to 1000° F. Figure 40 shows a Rockwell hardness plot of parent metal, heat affected zone, and weld material for the same range of heat treatment.

3.2.2 D6AC Welded Data

Figure 26 is a typical weld procedure sheet giving the information for TIG welding D6AC.

Tensile results for welded D6AC plate specimens are given in Table XVII and plotted in Figure 27 for various tempering temperatures from 600° to 1100° F.

Round notched and unnotched tensile specimens of D6AC and AMS 6434 were tested and the results are given in Table XVIII. Some data missing from this table was due to breakage of extensometers during the testing.

Data from fracture toughness tests of welded D6AC plates is given in Table XX.

A metallographic study of D6AC weldments quenched and tempered from 600° F to 1200° F are provided in Figures 41 thru 48.

3.2.3 Maraging 18% Nickel Steel Welded Data.

A typical weld procedure for TIG welding Maraging 18% Nickel steel is shown in Figure 28.

Tensile test results for welded maraging 18% nickel steel plates from various heats including plate to forging weldments is given in Table XIX. The welding in all cases had been done by the TIG method using parent metal composition as filler wire.

The effect of aging temperatures on the mechanical properties of weldments made in 200 Ksi strength maraging steel plate is shown graphically in Figure 29.

Figures 30 and 31 depict hardness surveys of parent metal 250 Ksi and 200 Ksi welded with various filler wire compositions. This survey was taken to depict the effect of using weld wire of higher titanium content than in the parent plate material.

Fracture toughness data for welded maraging 18% nickel steel is presented in Table XX.

A metallographical study of welded 18% nickel maraging steel is presented in Figures 49 thru 55.

Typical plasma arc burned 1/2 in. thick maraging steel plates are shown in Figure 56. Tensile test data was taken on plates plasma arc burned, then welded after removing loose scale by wire brushing. The data from these tests is given in Table XXI.

A series of tests were made on weld shrinkage of 1/2 in. thick plates butt welded with "J" grooves welded half from each side and one side only. Data from these tests is given in Figure 57.

4.0 Welding and Weld Joint Strength.

4.1 Welding Process Evaluation.

Exploratory welding tests were conducted on plates 1/2 in. thick of three grades of 18% nickel steels, D6AC and AMS 6434. Since booster motor case construction the metal-arc-inert gas welding (MIG) and tungsten-arc-inert gas welding (TIG) were the oft recommended processes, all of this exploratory work was confined to evaluation of these two welding processes. Fusion welding using the submerged arc was tried using available parent metal electrodes in the case of AMS 6434 and D6AC but was later abandoned since the fluxes available appeared unsuitable.

The metal-arc-inert gas (MIG) welding of maraging 18% nickel steel produced some cracking in 1/2 in. thick butt welded plates when parent filler wire was used. This difficulty was remedied by using overmatched composition (high titanium content) filler wire. A few tensile tests conducted on metal-arc-inert gas manually welded plates indicated that the maximum joint efficiency that could be consistently obtained was limited to 90 per cent. Occasionally, some weld tension test specimen exhibited joint efficiency up to 94 per cent but no higher. Metallographic examination of MIG welded plates indicated considerable amounts of austenite in the weld zone and in the wide, uneven heat affected zone. It was surmised that this untransformed austentite may have some influence on weld joint efficiency.

Subsequently, when welds made using tungsten-arc-inert gas (TIG) welding process showed substantial improvements over the MIG welds, efforts were directed to using only this technique for producing high efficiency welds in plates of all experimental steels. The TIG method produced welds in maraging compositions which showed lowest amount of reformed austentite and a relatively narrow heat-affected zone. Even under relatively high restraint conditions, TIG method produced sound crack-free welds in maraging steels. See metallographic study figures 49 thru 55.

By comparing parent metal data Table XII and welded tensile test data Table XIX it is seen that weld efficiencies of 95 to 100 per cent were obtained with the TIG welding method. Particular care was taken to maintain low interpass weld temperatures (below 250^{o}F), a high rate of gas flow, and high secondary amperage with a fast rate of travel on the weld head.

Data from various sources that have MIG welded indicated weld joint efficiencies of 90%. Data examined is from International Nickel Company - Technical Paper 334 - February 16, 1962; Battelle Memorial Institute reports - July 2, 1962 - DMIC Memorandum 156, and Linde Company, Division of Union Carbide.

Fracture toughness G_c values of welded plates are high when weld rod of similar chemistry to the plate is used. (4 & 5 table XX) When weld rod of the 280 Ksi level is used with 200 Ksi plate material, the G_c values drop to a critical range of 400 or below. (1, 2 and 3 table XX).

Weld shrinkage data was taken on two typical weld groove configurations in 1/2 in. plate. (Figure 57). Shrinkage of approximately .060 in. on a plate grooved one half from each side and .070 when grooved from one side only were experienced. These results are typical and similar to that experienced on AMS 6434 and D6AC.

Oxy-acetylene burning is unsatisfactory. Plasma arc burning was found to be very successful. Typical burned edges are shown in figure 56. The heat affected zone is shallow and aging of the heat affected area is minor. Rc hardness traverse across the heat affected area showed a maximum of R_c 40. Tests were made to examine the effect of welding directly on the burned edge. Preparation was made by plasma arc burning and wire brushing to clean. Results of this test are shown in Table XXI.

AMS 6434 is readily welded in both the annealed and heat treated condition using both TIG and MIG methods. Weld rod should always be vacuum arc remelt. Preheat of 400^{o} F is required to prevent weld cracks. A typical weld parameter sheet used in this study for the TIG welding process is shown in Figure 22. Consistent 100% weld efficiencies are obtained in yield and tensile strengths as determined by test bars breaking outside the weld and heat affected zone consistently. Curves from many tensile test bars, Figure 24 and Figure 25 indicate that yield strength and tensile strength generally remain constant from thin sheet to thick plates. Y.S. 190 to 210 Ksi and T.S. 220 to 250 Ksi being the general pattern.

AMS 6434 may be burned by the conventional oxy-acetylene method, however, since this material hardens somewhat in air cooling, the heat affected zone will be hardened and difficult to machine. If burned by the plasma arc process, the heat affected zone appears to be very shallow and may be removed by any of the conventional methods for removing mill scale.

D6AC contains more carbon (.40) and is therefore the most difficult to weld of the materials studied. The susceptibility of D6AC material to cracking along the fusion zone due to the high carbon content is evident in the microstructures Figures 41 and 45. With care, this material is weldable both annealed and heat treated by the TIG and MIG processes. Weld rod should always be vacuum arc remelt. Preheat of 625° F with a post heat of 600° F for 1 hour and dropping 100° F per hour to room temperature is highly recommended. A typical weld parameter sheet for this material is shown in Figure 26.

Consistent 100% weld efficiencies are obtained in yield and tensile strengths, as indicated by test bars breaking outside the weld and heat affected zones.

Burning D6AC by the oxy-acetylene method produces a very hard heat affected zone. Most machining methods are unsatisfactory in removing the material at the burned edge. Plasma arc burning leaves a very hard edge only a few thousandths deep which is readily removed by grinding or by machining if the machine cut is deeper than the hardened surface.

4.2 Effect of Weld Filler Wire Composition on the Efficiency of Weldments in Heavy Section.

In fusion welding of maraging 18% nickel steels, development of parent metal strength in the weldments has been a problem. It had been suggested that use of base metal composition filler wire containing slightly higher titanium content improves weld efficiency. In practice, however, such higher weld efficiency was obtained at the sacrifice of ductility and fracture toughness. A hardness survey conducted on 250 Ksi maraging 18% nickel steel 1/2 in. plate sections welded with 250 Ksi strength maraging 18% nickel steel filler wires is presented in Figure 30.

This hardness survey indicates that a 300 Ksi strength filler wire produces considerable hardness variation in the weld zone and heat affected zones compared with the parent plate material in the as-welded and also the as-welded and aged conditions.

4.3 Hardness and Metallographic Studies of Heat Treated TIG Weldments.

A hardness survey on the welded plate specimens of the three types of steels, AMS 6434, D6AC and 18% Nickel Maraging Steel was made to get a better understanding of the strength variation in the weldments and heat affected zone in comparison with the parent plate material.

Since a 200 Ksi yield strength level plate was readily available, butt welds on two sets of plates were made using filler wire containing 0.40 per cent titanium.

The hardness study conducted on welded and aged sections including the parent metal, weld heat affected zone and the weld deposit is summarized in Figure 31.

It is to be noted from the variation of hardness that a uniform yield strength level of 200 Ksi is not easily obtainable in the composite weldment. This hardness survey of welded plate sections of 200 Ksi maraging steel aged in the temperature range 850° F through 1100° F indicates further that the hardness peaks in the narrow range between 900° F and 950° F (Figure 31). The optimun aging temperature for this steel, therefore, is 925° F, allowing for slight variations of temperature in the aging furnace.

Metallographic studies made of welded sections aged at various temperatures and presented in Figures 49 through 55 is the most comprehensive work available on 1/2 in. plate sections. In the optimally aged specimens the microstructures in the parent metal, heat affected zone and the weldment are nearly the same in terms of fineness of the structure, particle size of the precipitates, and the amount of austenite appearing in the various zones.

The results of a hardness survey conducted on D6AC welded plate sections using base metal filler wire and TIG process, are summarized in Figure 40. A similar hardness survey data for AMS 6434 1/2 in. plate, "ring-shell" assembly are also presented in Figure 40.

Microstructures seen in D6AC plate weldments in as quenched, and various quenched and tempered conditions are depicted in Figures 41 through 48. The susceptibility of D6AC 0.400 in. plate material to cracking along the fusion zone is evident in Figures 41 and 45. This type of cracking usually occurs after quenching and not during welding.

A careful evaluation of microstructures of D6AC weldments tempered in the range 600° F through 1200° F indicates that the microstructure of the joint becomes similar in appearance to that of the parent plate when tempering is done around 1000° F.

A similar microstructural study of weldment of AMS 6434 was also conducted and the changes occurring in the microstructure from the as quenched state and when tempering is done in the range 400° F through 1000° F are depicted in Figures 32 through 39. The microstructure of the AMS 6434 welded joint is finest when tempering is done at 400° F, 500° F, or 600° F. When tempering is done at higher temperatures, the microstructure in the AMS 6434 plate welds becomes coarse, lamellar, and much different in appearance from that of parent plate material.

5.0 Machining

5.1 AMS 6434

Experience with this material indicates that all the machining operations can be performed in the annealed and the heat treated condition. These operations including milling, drilling and tapping, sawing, and single point tool cutting. In general, high speed steel or carbide tools can be used on the material in the annealed condition with cutting speeds up to 280 Ft./min. using single point tools and coolant. In the hardened condition, carbide mills, cobalt drills, friction sawing and carbide single point tools were the most satisfactory. Speeds up to 120 ft./min. using carbide single point tools with .100 in. depth of cut and .012 feed were practical.

5.2 D6AC

The comments on machining AMS 6434 apply to D6AC. There seems to be no significant difference in the machinability of these two alloys in either the annealed or the heat treated condition.

5.3 Maraging 18% Nickel

Because of the high nickel content and the toughness of this material, there was considerable question as to the machinability in both the annealed and the aged condition.

Various machining operations were examined.

a. Milling was successful using high speed steel cutters on the material in the annealed condition and carbide on the aged material.

b. Drilling and tapping have been the most difficult operations on high strength steels in the past. In 240 Ksi material at 51 R_c, 3/8, 1/2 and 3/4 tap size high speed steel drills were used at 210 Rpm with a standard cutting oil. These holes were then tapped with 2B and 3B cobalt taps both by machine and by hand. Drilling and tapping appeared to be similar to that experienced with 4135 but considerably easier than that experienced with either AMS 6434 or D6AC.

c. Maraging 18% nickel steels saw readily with standard saw blades when the material is in the annealed condition. However, in the aged condition (51 R_c) sawing becomes very difficult. The only successful method appears to be friction sawing with a blade speed of 13,000 to 15,000 SF/min. At this speed 1/2 in. thick plate can be sawed at one foot per minute.

d. Single point tool cutting was examined on lathes, boring mills and planers. In the annealed condition, 250 Ksi material was machined using both high speed and carbide tool bits. Typical cutting was done at 180 to 240 ft. per min. using 1/4 in. depth of cut and .015 feed on boring mills. In the aged condition, only lathe and boring mill operations were successful. Feeds and speeds similar to those used on AMS 6434 and D6AC were found to be successful.

6.0 Forming (1)*

Both AMS 6434 and D6AC have been successfully formed by making heads and rolling cylinders. Maraging 18% nickel steel appears to have no significant problems in this area. Cylinders 5/8 thick x 120 in. diameter have been rolled and welded. Head sections for a gored head have been formed successfully. See photographs of gore sections and dollar plate, Figure 58 and Figure 59. The only condition observed to be different in maraging steels is more spring back in the forming operations than observed with either AMS 6434 and D6AC.

7.0 Heat Treatment

7.1 AMS 6434

P. P. 2.3 gives the heat treat cycles used on the various materials examined. The curves Figure 24 and Figure 25 showing yield strength and tensile strength plotted against material thickness are very significant. In particular, they show that with this material heat treated to a Y. S. of 190 to 210 Ksi and a T. S. of 220 to 250 Ksi that the values remain relatively constant from thin sheet to 5/8 thick plate. This is a clear indication of through hardening ability which is most important in plate construction of high strength solid propellant rocket engine cases.

7.2 D6AC

D6AC heat treats to a slightly higher level than AMS 6434 when the tempering temperature is held at 600° F. However, when a tempering temperature of 1000° F is used the Y. S. and T. S. values are approximately the same as AMS 6434 and the elongation and reduction of area of the material is considerably improved.

*(1) Preliminary information on forming 18% Nickel Maraging Steel results from work performed on AF contract AF04(611)8525

7.3 Maraging 18% Nickel

Maraging steels are completely through hardening, even in forgings 2 in. thick. The strength level depends on aging time and temperature for any particular chemistry. The very low carbon and 900° F aging temperature eliminates all problems of decarburization or carburization. The highest yield strengths were achieved at an aging temperature of 925° F with very slight loss in toughness.

A further study was made on the stability of maraging 18% nickel steel during the aging process. Results of this test are given in Figure 60. The exact shrinkage as a result of aging was .000378 in./in. as measured on a 24 in. long bar. Further, it should be noted that hole sizes and flatness of the part remained astonishingly constant in this test. We feel that many possibilities of finish machining detail parts before welding and aging can be done on large cases by exploiting the dimensional stability of this material. This can lead to considerable cost reduction over present concepts of fabrication of metal parts.

8.0 Discussion

To evaluate the mechanical properties and fabrication techniques used on the three materials, AMS 6434, D6AC, and Maraging 18% nickel steel, many tests were required. Figure 61 shows approximately 1/3 of the test samples used. The evaluation was done in an attempt to clearly define the best candidate material for high strength solid propellant rocket engine cases. It is felt that at this time none of the materials tested can be completely eliminated, however, certain advantages do establish the best candidate material.

Welding of Maraging 18% nickel steel is considerably easier than either AMS 6434 or D6AC. First, it is not as susceptible to cracking or porosity. Second, 18% nickel maraging steel is welded cold with no pre-heat or post heat. AMS 6434 with a pre-heat of 400° F is not too difficult a problem. However, D6AC with a pre-heat of 625° F is a considerable problem both in maintaining this temperature on a large part and for the personnel exposed to a large part at this temperature. The susceptibility of D6AC to cracking during welding and heat treating makes it the poorest risk in this area.

Examining all the machining operations that are required to build a case, AMS 6434 and D6AC appear to be very similar. Maraging 18% nickel steel is somewhat easier to machine and due to the aging process to acquire strength rather than austenize and quench with the resultant distortions, it appears that certain areas may be able to be finish machined in the annealed condition.

During the heat treat cycle, D6AC has a definite advantage in the use of a 1000° F tempering temperature. At this temperature, some straightening can be accomplished to overcome principally the distortions that come from the austenize and quench operation. AMS 6434 must necessarily be used as it comes dimensionally from the quench since very little straightening can be done at the 425° F tempering temperature. Maraging 18% nickel steel requires additional tooling and labor during all fitting, forming and welding fit up processes since no heat can be used to help in any of these processes unless a complete re-anneal cycle of 1 hour at 1500° F is used. However, the heat treating furnaces required for maraging steel are much less expensive relatively since no controlled atmospheres in the furnace are required and the aging temperature is limited to 925° F.

An evaluation of the tensile of parent plate materials tested in this program indicates that it is relatively easy to obtain yield strength levels around 200,000 psi in the case of AMS 6434, D6AC, and the maraging 18 per cent nickel steels.

In welded plates, however, the maraging 200 Ksi steel did not develop yield strength much above 180,000 psi. For booster case applications, therefore, the 250 Ksi steel is proposed. Future studies of maraging steels for booster case application should be concentrated upon the 250 Ksi composition in both plate and large forged and rolled ring sections.

From mechanical strength view point, welded D6AC and AMS 6434 do not seem to have any undesirable features. D6AC has a tendency to crack in the fusion zone of the weld joints; therefore, careful handling of heavy sections to be welded and good fixturing during welding appears very necessary.

Fracture toughness studies conducted on parent plate and welded plates of three maraging grades of steels have indicated that the 200 Ksi and 250 Ksi grades possess adequate fracture toughness. G_c values of 800 ipsi and 500 ipsi are considered adequate for 3/8 in. and 1/2 in. thick plates. On this basis, AMS 6434 has marginal fracture toughness in the parent plate; D6AC possess somewhat higher fracture toughness value. The weldments in all grades of steels tested in this program except the 300 Ksi maraging composition, have exhibited either equal or greater fracture toughness value than the parent plate. This apparent inversion of results in welded heavy sections is contradictory to similar observations in sheet material. The 300 Ksi maraging composition can be classed with the other higher carbon brittle grades of high strength steels.

The fracture toughness data presented must be considered as tentative for the present. The entire subject of fracture toughness testing of heavy gage plate material needs a careful review as to specimen geometry, size of the specimen in relation to plate thickness, the notch acuity, the method of notching and the calculation of the various fracture test parameters. Much exploratory work needs to be done urgently before any extensive fracture toughness evaluation programs are initiated for steel plate materials.

The high G_c values obtained for welded 3/4 in. thick D6AC plate may be attributed to the fact that a short specimen was used in the test. In evaluating the fracture toughness of welded plates, it is of importance to get a G_c test value for unwelded or parent plate material for direct comparison. Such an evaluation using two specimens, one welded and the other of parent material would be more significant in determining the weld joint efficiency and parent material integrity.

In regard to selection of a welding process for the construction of booster cases using 3/8" and 1/2" thick plates, the tungsten-arc-inert gas welding technique seems to be readily applicable.

Sufficient exploratory work has not been done to date in the use of metal-arc-inert gas and submerged arc welding in fusion welding of ultra-high strength steel plates. These processes are of promise in this application and are therefore worthy of extensive investigation.

The crack sensitivity noticed in D6AC weldments can be traced to three factors; namely, incompartibility of weld filler wire, high restraint, excessive heat input. These problems indicate the need for additional process development types of research in welding plates of thickness greater than 3/8 in.

9.0 Conclusions

First it must be recognized that at the time of writing this report, 19 sections of 120 in. diameter segmented motor cases have been built and successfully tested. These sections were all made from AMS 6434. Three of these sections have been loaded and static fired. Work is in progress that will shortly result in the testing of 120 in. diameter sections of the rolled and welded type in both D6AC and maraging 18% nickel steel. Assuming that both of these tests will be successful, it is felt that this study has shown the following:

a. Maraging 18% nickel steel 250 Ksi level is the most favorable candidate steel for large solid propellant rocket engine cases.

b. AMS 6434 would be the second choice, based primarily on reliability in welding.

c. D6AC has evaluated well on mechanical and physical tests and can be used if care is taken in the welding operations and adequate non-destructive testing is done to assure sound welds in the finished product.

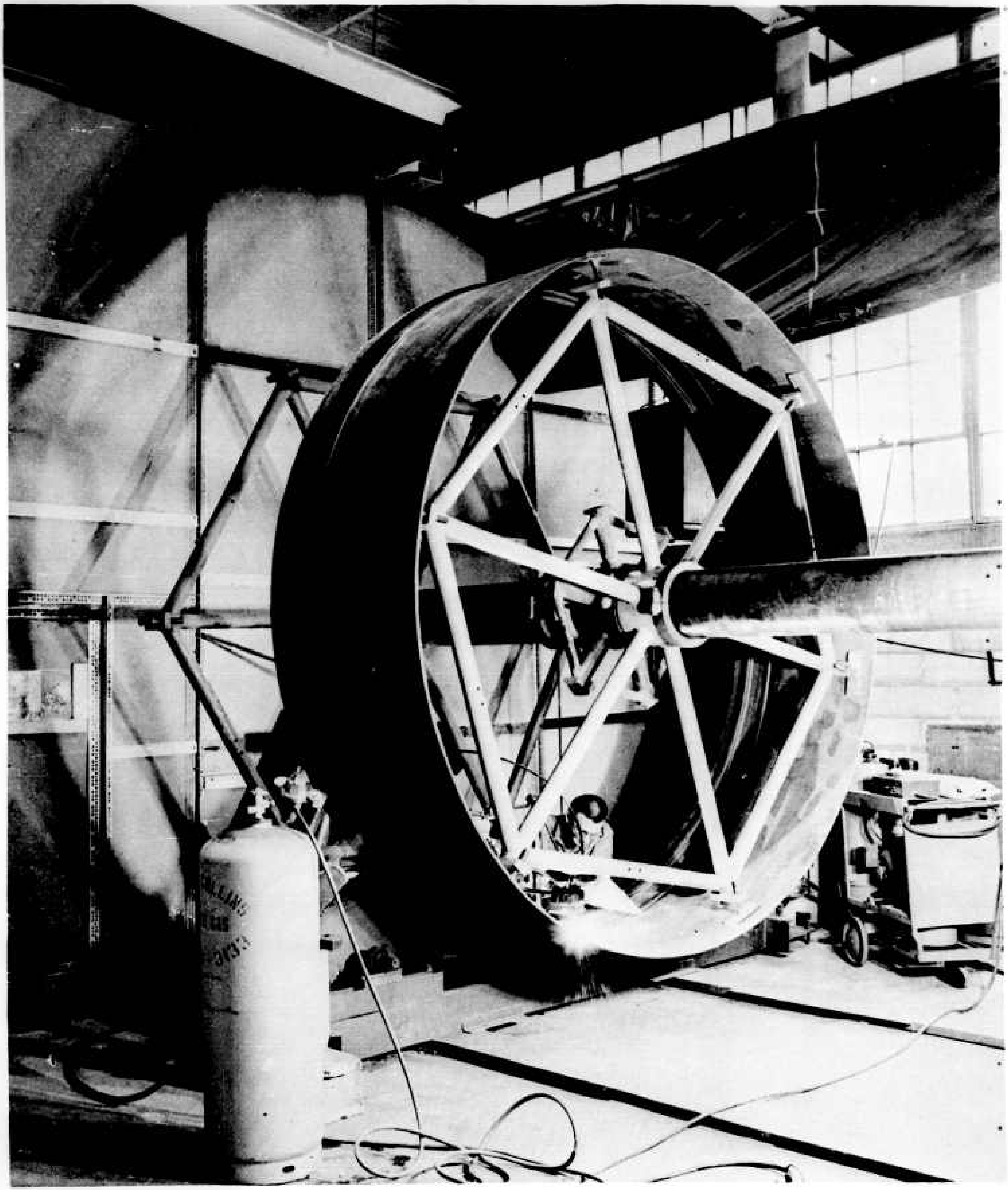


Figure 1. Ring Shell Assembly 120 in. Dia.
Girth Weld

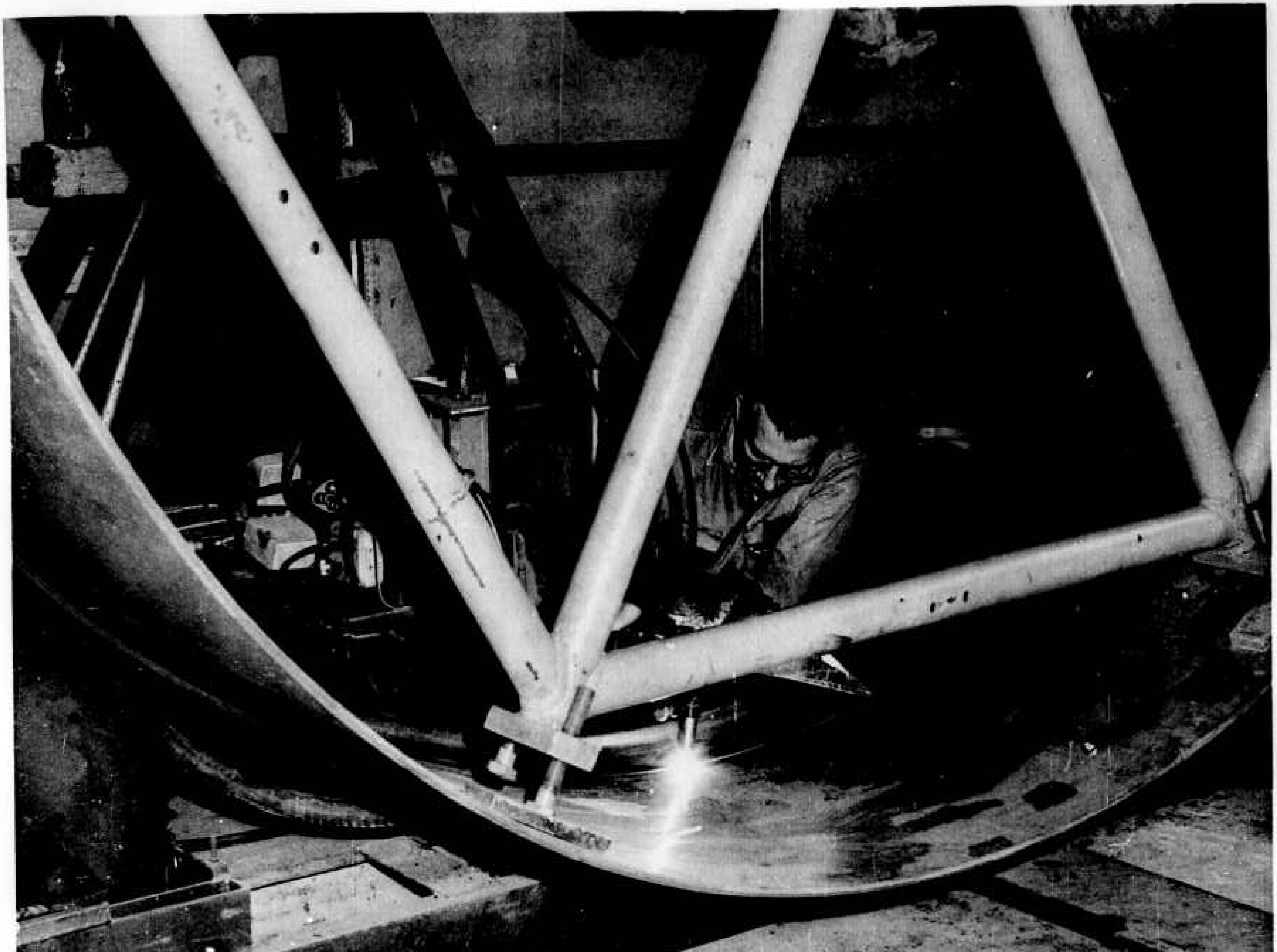


Figure 2 Ring Shell Assembly 120" Dia.
Girth Weld

TABLE I

CHEMICAL ANALYSIS OF WELD WIRE

AMS 6434

Heat – W-22138

D6AC

Heat-061257

C – .48 Mn. – .83 Si. – .26 P. – .008 Su. – .010
Cr. – 1.15 Ni. – .43 Mo. – .94 V – trace

MARAGING

Heat – 16524.33

C. – .014 Mn. – .01 P. – .003 S. – .003 Si. – .02
Ni. – 16.5 Mo. – 4.09 Co. – 8.11 Ti. – .42 Al. – .10
H2 – 3.8 ppm

Heat – 06919

C. – .02 Mn. – .04 P. – .006 S. – .009 Si. – .09
Mo. – 4.20 Ni. – 17.94 Al. – .02 Co. – 9.74 Ti. – .60

Heat – W-24236

C. – .006 Mn. – .04 P. – .001 S. – .005 Si. – .054
Ni. – 17.92 Mo. – 4.34 Cu. – .005 Ti. – .35 Al. – .15
B. – .003 Co. – 7.38 Zr. – .006

Heat – V-187

C. – .02 Si. – .01 Mn. – .04 S. – .004 P. – .003
Ni. – 18.44 Co. – 7.95 Mo. – 4.60 Al. – .11 Ti. – .49

TABLE II

CHEMICAL ANALYSES OF STEEL PLATES AND FORGINGS USED IN THIS STUDY

Maraging Steels

Heat 23831 (300 Ksi)

C	Mn	P	S	Si	Ni	Al	Mo	Co	Ti	B
0.008	0.015	0.001	0.003	0.05	18.61	0.13	5.00	9.05	0.71	0.002

Heat 23560 (200 Ksi)

C	Mn	P	S	Si	Ni	Al	Mo	Co	Ti	B
0.026	0.010	0.008	0.011	0.064	18.72	0.060	4.59	7.87	0.24	0.004

Heat X-13371 (250 Ksi)

C	Mn	P	S	Si	Ni	Al	Mo	Co	Ti	B
0.02	0.04	0.004	0.009	0.05	17.83	0.11	4.70	7.41	0.46	0.004

Heat 120D163 (250 Ksi)

C	Mn	P	S	Si	Ni	Al	Mo	Co	Ti	B
0.017	0.07	0.006	0.004	0.16	18.04	0.12	4.70	8.10	0.50	0.003

Heat 4780-70979 (200 Ksi)

C	Mn	P	S	Si	Ni	Al	Mo	Co	Ti	B
0.018	0.02	0.001	0.009	0.01	18.06	0.09	3.10	8.56	0.17	----

Heat 04524 (240 Ksi)

C	Mn	P	S	Si	Ni	Al	Mo	Co	Ti	B
0.021	0.07	0.004	0.006	0.09	18.38	0.07	4.82	7.82	0.35	----

LOW ALLOY STEELS:

Heat 9207803 - D-6-AC - Composition not available

Heat X062-9203 - D-6-AC - Composition not available

Heat 3950816 D-6-AC

C	Mn	P	S	Si	Ni	Cr	Mo	V
0.47	0.63	0.007	0.005	0.30	0.53	1.01	0.95	0.09

TABLE II (Continued)

Heat 319494 AMS 6434

C	Mn	P	S	Si	Ni	Cr	Mo	V
0.38	0.73	0.013	0.006	0.56	1.80	0.80	0.37	0.20

Heat 13736 AMS 6434 - Composition not available

TABLE III

SIZE OF STEEL SAMPLES AND NUMBERS OF MECHANICAL TEST SPECIMENS PREPARED

Steel Sample Size (in.)	Material	Heat Number	Tensile Specimens Flat		Tensile Specimens Round		Notched		Charpy Specimens		Fracture Toughness Specimens	
			Welded	Unwelded	Welded	Unwelded	Welded	Unwelded	Welded	Unwelded	Welded	Unwelded
.360 x 18 x 32	Maraging 18 Ni (300 Ksi)	23831		2		6		6		12		2
.400 x 8 x 25	Maraging 18 Ni (200 Ksi)	23560				3		3		6		1
-----	Maraging 18 Ni (200 Ksi)	X13371		4						4		
1/2 x 24 x 36	Maraging 18 Ni (250 Ksi)	120D163	4								2	
1/2 x 12 x 72	Maraging 18 Ni (200 Ksi)	4780-70979	18	32							3	
-----	Maraging 18 Ni (250 Ksi)	04524	8	4								
3/8 x 24 x 56	D-6-AC	9207803	3	12	5	1	4	2			4	
3/8 x 12 x 23	D-6-AC	X062-9203	8									
3/4 x 12 x 36	D-6-AC	3950816	1			2		2		7		1
1/2 x 24 x 30	AMS 6434	319494		8	1	1	2	2	3	10	2	2
1/2 x 14 x 24	AMS 6434	13736	10	4								

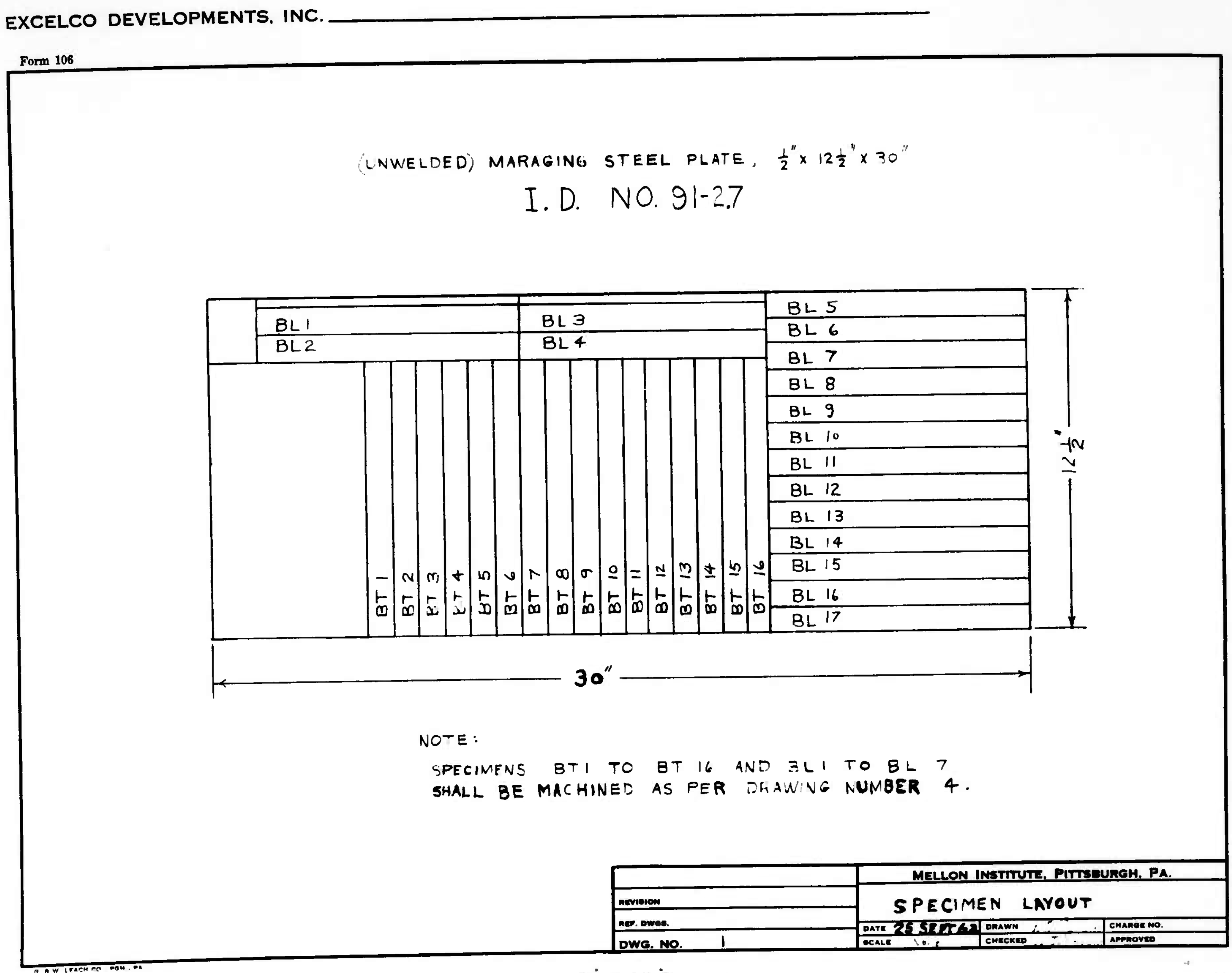

EXCELCO DEVELOPMENTS, INC.
Form 106
(UNWELDED) MARAGING STEEL PLATE, 1/2" x 12 1/2" x 30"
I. D. NO. 91-27
BL 1
BL 2
BL 3
BL 4
BL 5
BL 6
BL 7
BL 8
BL 9
BL 10
BL 11
BL 12
BL 13
BL 14
BL 15
BL 16
BL 17
BT 1
BT 2
BT 3
BT 4
BT 5
BT 6
BT 7
BT 8
BT 9
BT 10
BT 11
BT 12
BT 13
BT 14
BT 15
BT 16
12 1/2"
30"
NOTE:
SPECIMENS BT 1 TO BT 16 AND BL 1 TO BL 7
SHALL BE MACHINED AS PER DRAWING NUMBER 4.
MELLON INSTITUTE, PITTSBURGH, PA.
SPECIMEN LAYOUT
REVISION
REF. DWGS.
DWG. NO. 1
DATE 25 SEPT 62
SCALE
DRAWN
CHECKED
CHARGE NO.
APPROVED

Figure 3

EXCELCO DEVELOPMENTS, INC.

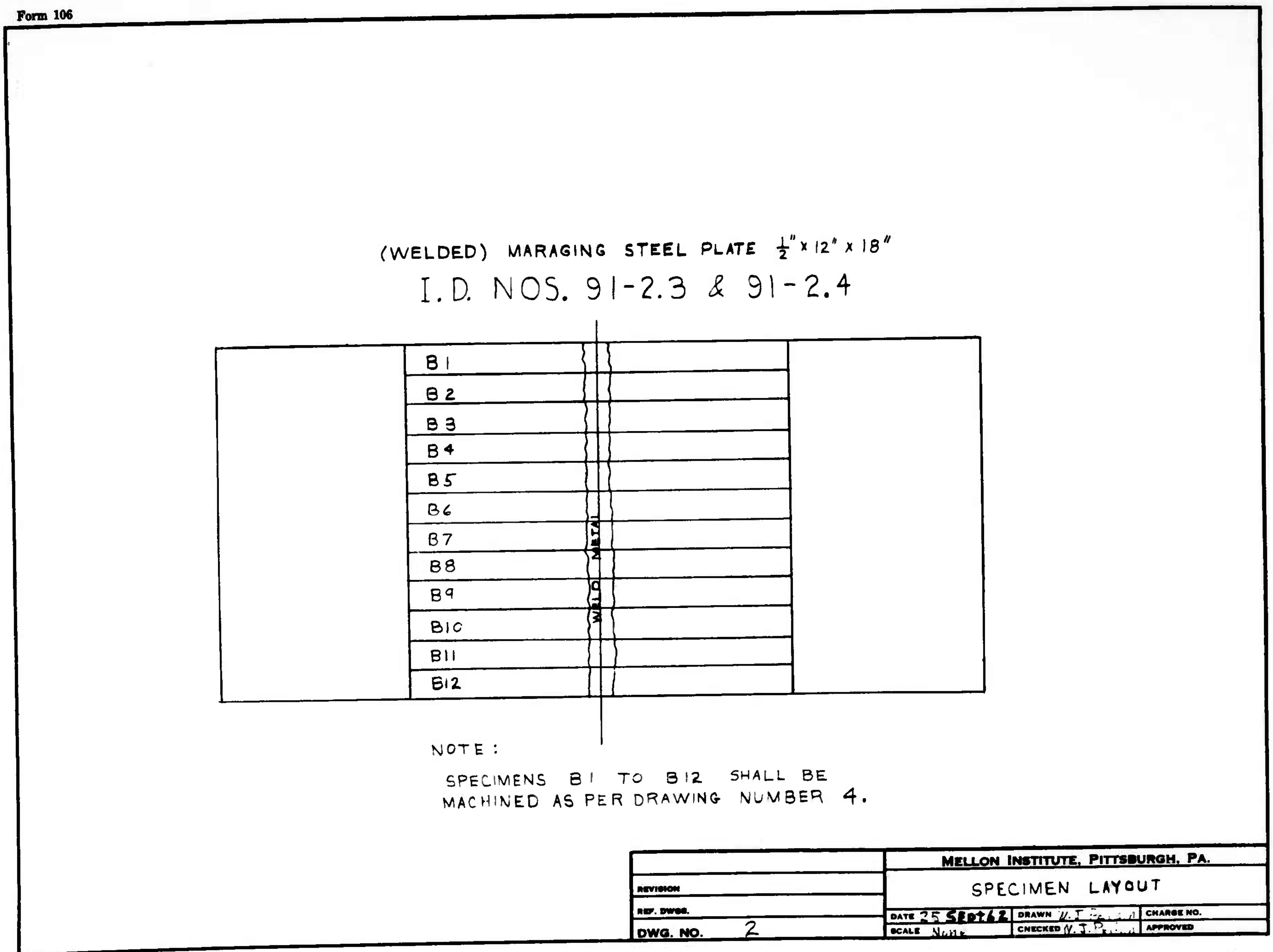


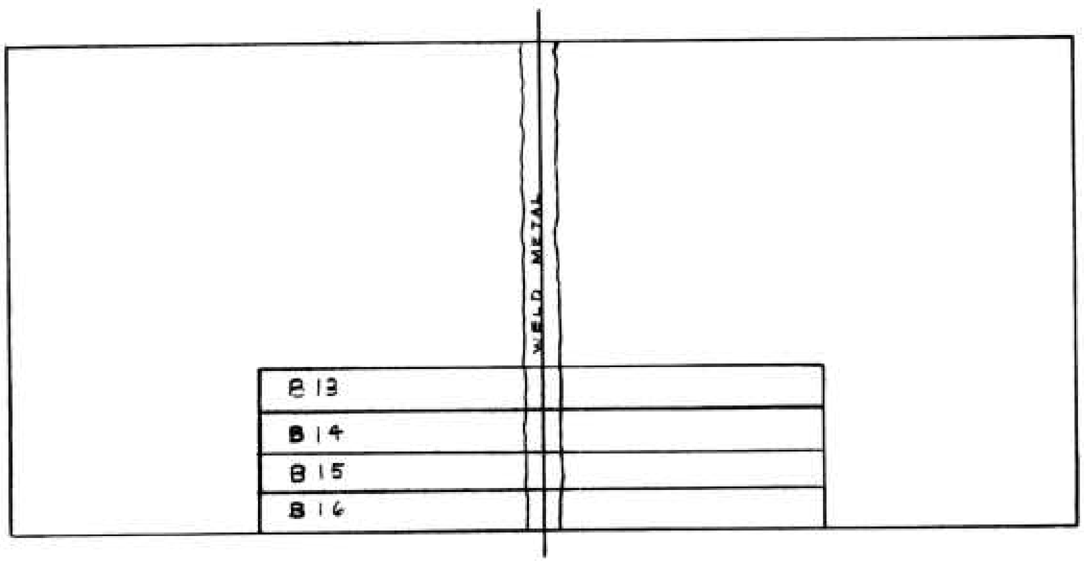
Figure 4

EXCELCO DEVELOPMENTS, INC.

Form 106

(WELDED) MARAGING STEEL PLATE, $\frac{1}{2}'' \times 12'' \times 18''$

I.D. NOS. 91-2.1 & 91-2.2



NOTE:

SPECIMENS B13 TO B16 SHALL BE
MACHINED AS PER DRAWING NUMBER 4.

	MELLON INSTITUTE, PITTSBURGH, PA.
REVISION	SPECIMEN LAYOUT
REF. DWGS.	DATE 25 SEPT. 62 / DRAWN / CHARGE NO.
DWG. NO. 3	SCALE / CHECKED / APPROVED

G. & W. LEACH CO. PGH. PA.

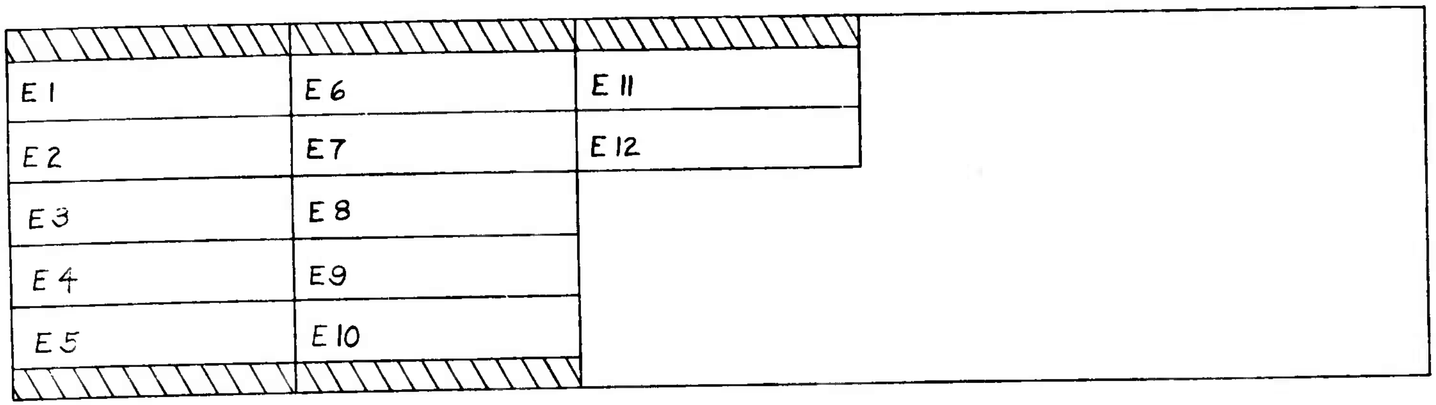
Figure 5

EXCELCO DEVELOPMENTS, INC.

Form 106

(UNWELDED) D6AC PLATE, 6" x 48" x 3/8"

I. D. NO. 91-5



NOTE:
SPECIMENS E 1 TO E 12 SHALL BE MACHINED AS PER DRAWING NUMBER 4.

	MELLON INSTITUTE, PITTSBURGH, PA.
REVISION	SPECIMEN LAYOUT
REF. DWGS.	DATE 10 Oct 62 · DRAWN J. Bramley · CHARGE NO.
DWG. NO. 7	SCALE None · CHECKED W. Persill · APPROVED

G & W LEACH CO PGH PA

Figure 6

EXCELCO DEVELOPMENTS, INC.

Form 106

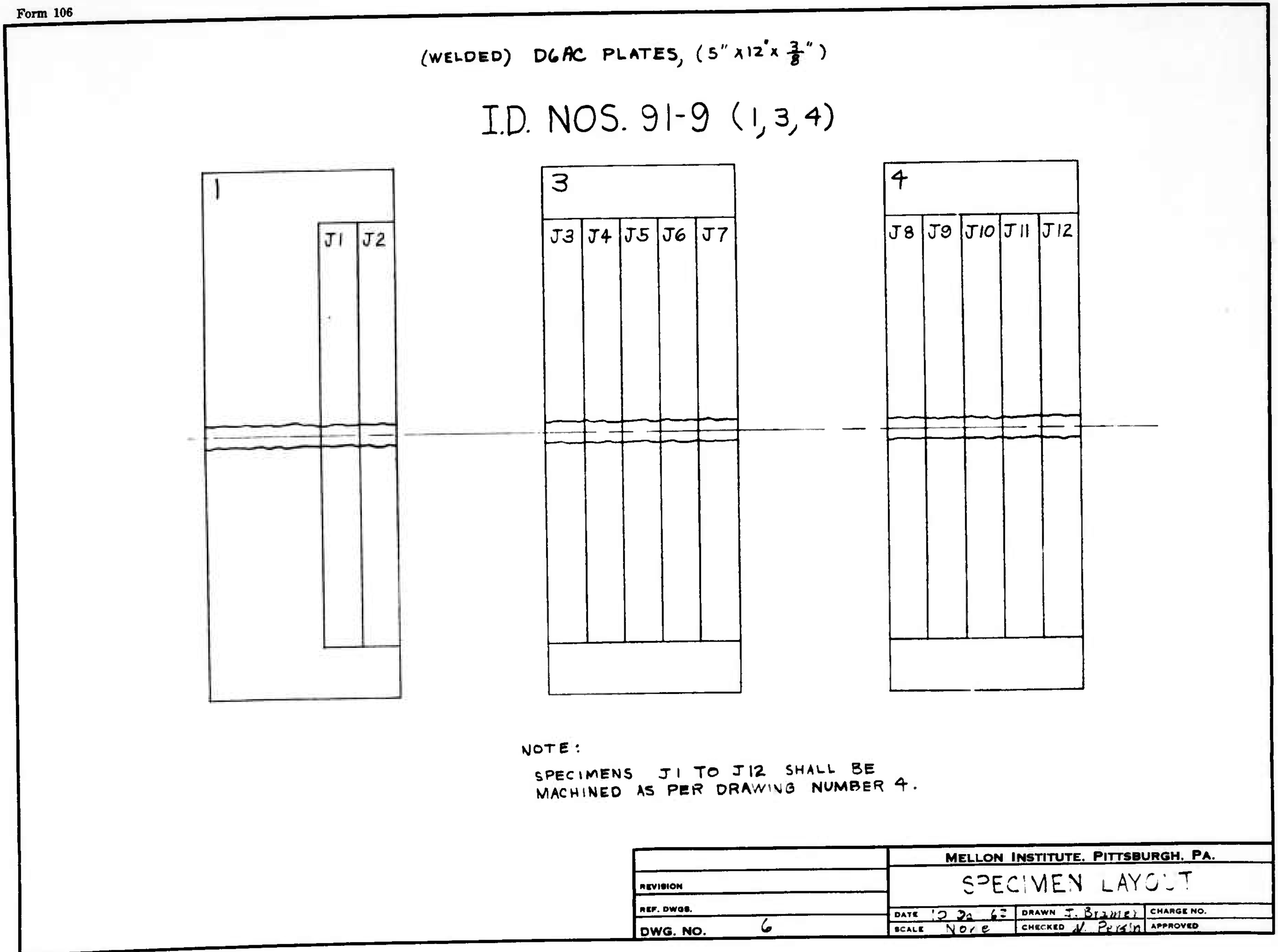
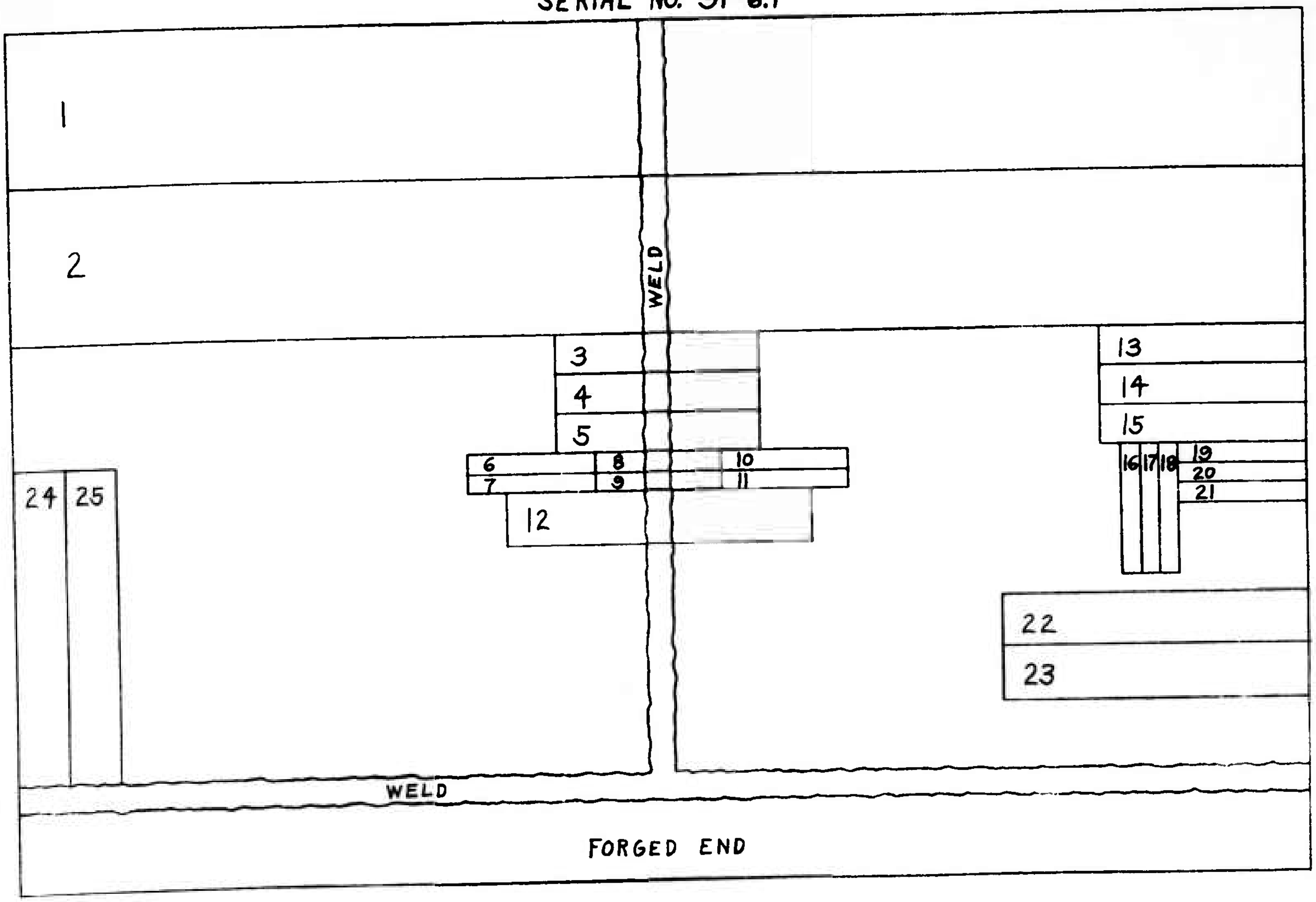


Figure 7

Form 106

AMS 6434, RING WELD ASSEMBLY,
SERIAL NO. 91-6.1



	MELLON INSTITUTE, PITTSBURGH, PA.
REVISION	SPECIMEN LAYOUT
REF. DWGS.	DATE / DRAWN / CHARGE NO.
DWG. NO. A-1	SCALE NO SCALE / CHECKED / APPROVED

G & W LEACH CO PGH., PA.

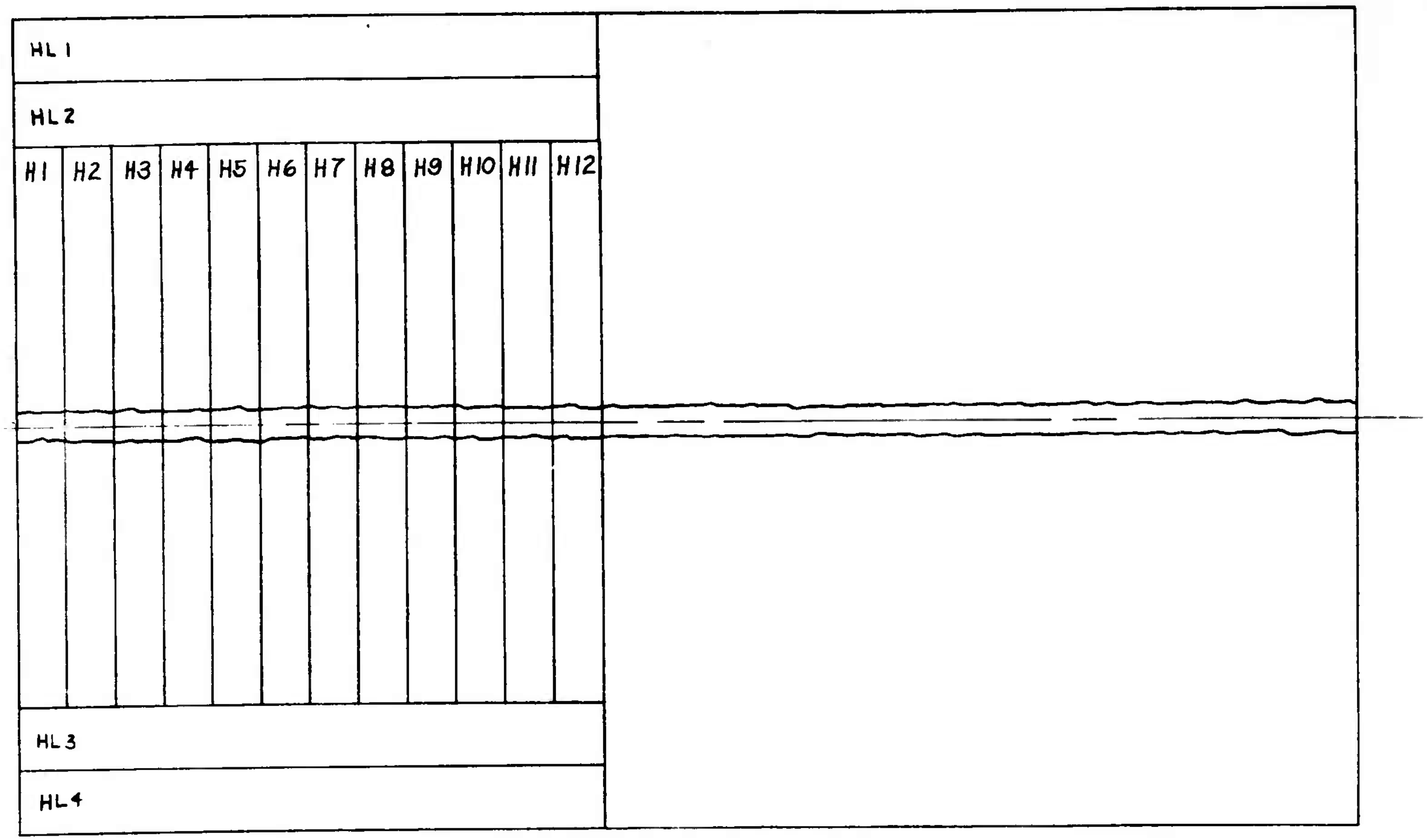
Figure 8

EXCELCO DEVELOPMENTS, INC.

Form 106

(WELDED) AMS 6434 PLATE, 24"x14"x½"

I.D. NO. 91.8



NOTE:

SPECIMENS H-1 TO H-12 AND HL-1 TO HL-4 SHALL BE MACHINED AS PER DRAWING NUMBER 4.

	MELLON INSTITUTE, PITTSBURGH, PA.
REVISION	SPECIMEN LAYOUT
REF. DWGS.	DATE 10 Oct. 62 · DRAWN J. Bramer · CHARGE NO.
DWG. NO. 5	SCALE None · CHECKED W. Persin · APPROVED

G & W LEACH CO. PGH. PA.

Figure 9

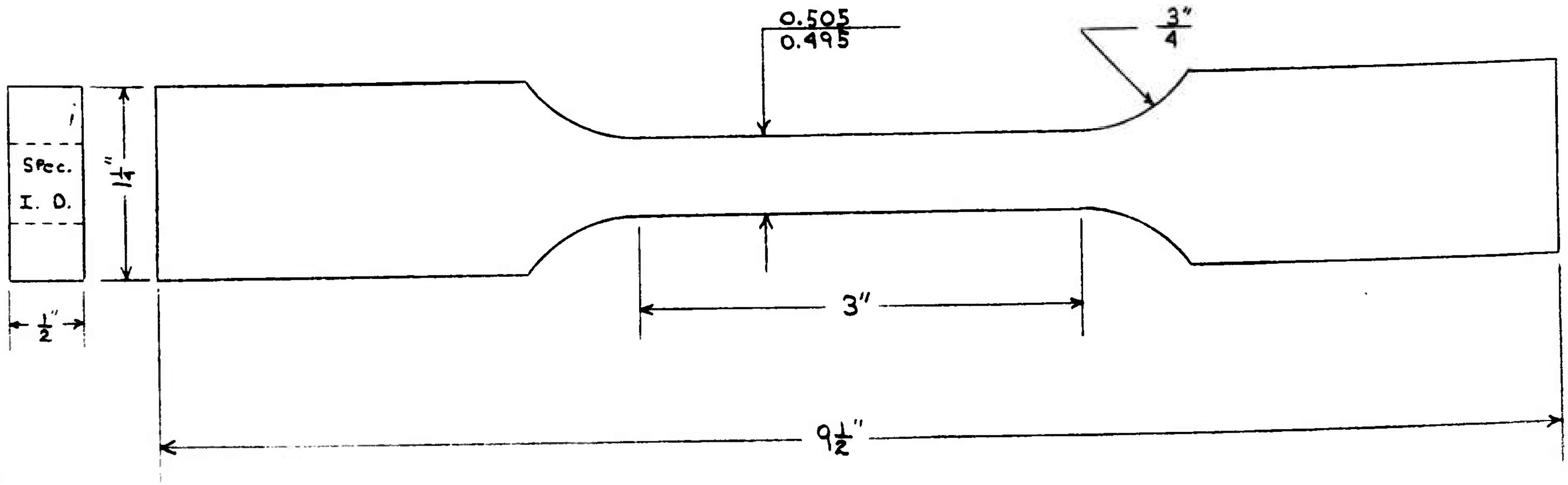
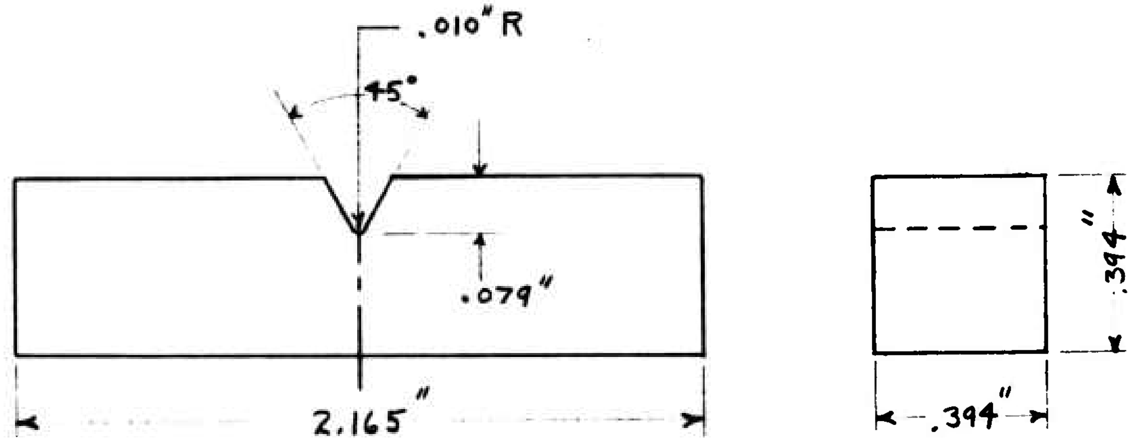


Figure 10. Geometry of parent plate and welded plate tensile test specimen.

EXCELCO DEVELOPMENTS, INC.



Tolerances : Decimals, ± .001"
Angles, ± 1°

Figure 11. Charpy Specimens of the above geometry have been taken from various locations in parent materials, weldments and H. A. Z.'s in both the transverse and longitudinal directions.

MELLON INSTITUTE, PITTSBURGH, PA.

CHARPY SPECIMEN

REVISION	DATE 14 Nov. 62	DRAWN Wm Persin	CHARGE NO.
REF. DWGS.	SCALE None	CHECKED Wm Persin	APPROVED
DWG. NO. A-2			

PLATE THICKNESS	A	B	C	D	E	α
1/4"	16"	4"	8"	1.20"	1/8	20°
3/8"	24"	6"	12"	1.80"	1/4	"
1/2"	32"	8"	16"	2.40"	"	"
5/8"	40"	10"	20"	3.00"	"	"
3/4"	48"	12"	24"	3.60"	"	"

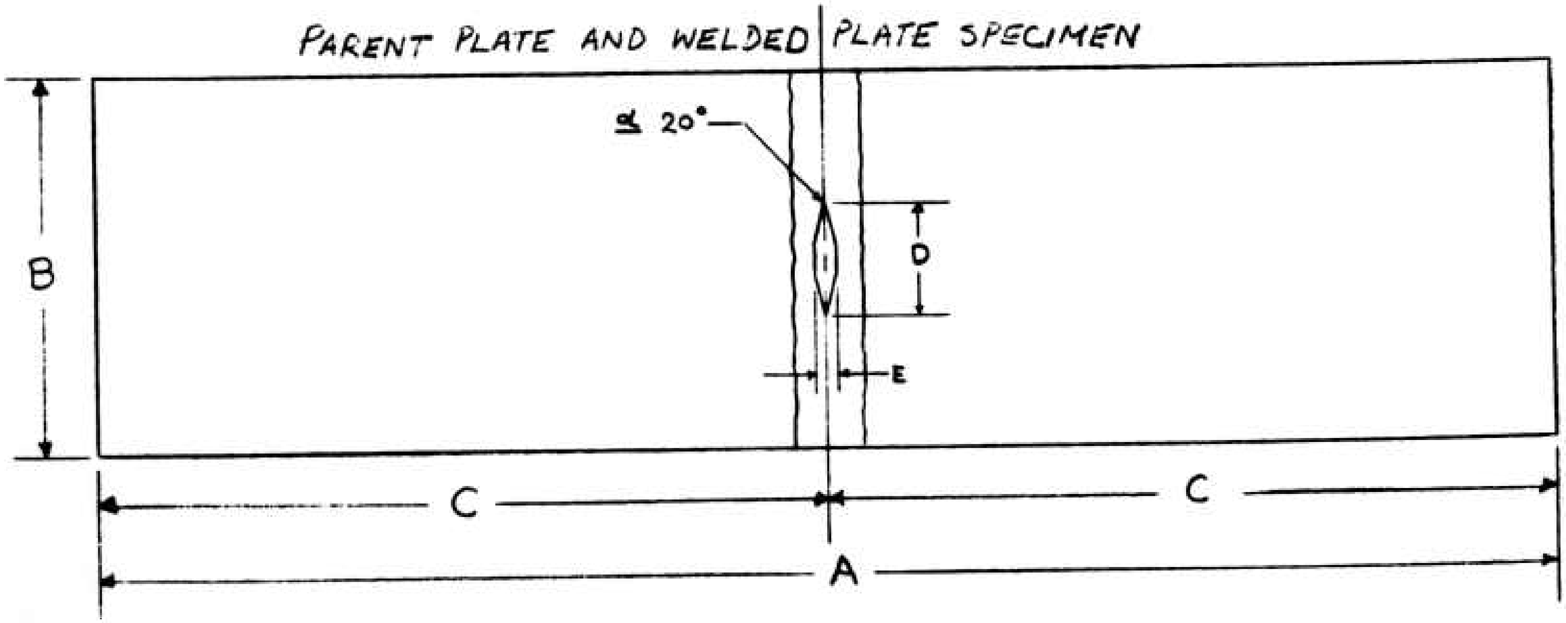


Figure 12. Geometry of fracture toughness test specimens used in this program.

MARAGING STEEL

WELD LOCALLY AGED

TABLE IV

PLATE MATERIAL: INT. NICKEL HEAT # 04524

MILL ANNEALED AND AGED AT 925° F. FOR 3 HOURS

Y.S. 246,600 T.S. 257,400 EL. 11.5%

RED. AREA 51.3%

WELD WIRE: INT. NICKEL HEAT # 16524.33

PLATE WAS PREPARED FOR WELDING AND AGED. R_c 49-50

WELDED AND THEN WELD LOCALLY AGED R_c 48-50

FOUR TENSILE BARS WERE PREPARED.

	1	2	3	4
Y.S.	241	239	239	240
T.S.	244	241	243	243
F.S.	273	306	259	276
RED. AREA	29	39	30	34
% EL. 1 In.	15	16	18	19
% EL. 2 In.	7.5	8	9	9.5

WELD EFF.

97 1/2% BASED ON Y.S.

94 1/2% BASED ON T.S.

TABLE V

TENSION TEST DATA FOR AMS 6434 FLAT SPECIMENS

1/2" x 1/2" Specimens Austenitized 1600F, Quenched in Oil and Tempered as Indicated

Heat No.	Tempering Temperature F	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent	Hardness R_c
319494	750	195	220	299	25.0	13.5	47	45.5
"	"	207	221	311	24.0	13.0	49	46.0
"	"	203	222	277	19.0	11.0	35	45.5
"	"	205	221	279	19.0	11.0	35	44.5
13736	500	207	244	288	13.0	8.0	23	45.0
"	600	188	214	247	13.0	8.0	21	46.0
"	700	210	232	261	13.0	8.5	22	43.0
"	800	191	205	245	16.0	9.5	26	41.0

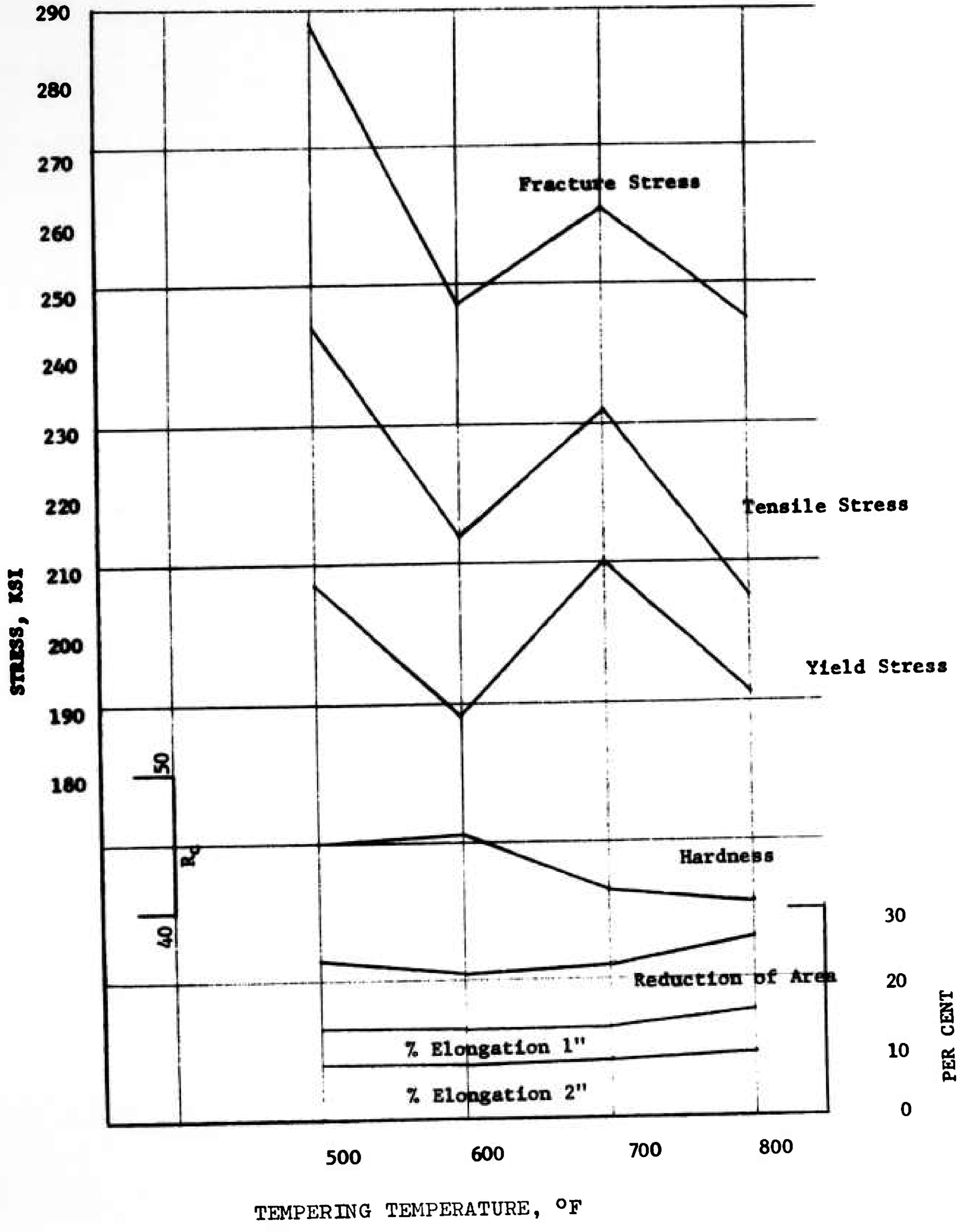


Figure 13. Effect of tempering temperature on the tensile properties of AMS 6434 (specimens austenitized 1600F, oil quenched and tempered as indicated).

TABLE VI

TENSION TEST DATA FOR AMS 6434 ROUND UN-NOTCHED AND NOTCHED SPECIMENS

Heat - 319494

Heat Treatment - Austenitized 1600F, Quenched in Oil and Tempered as Indicated

Specimen No.	Tempering Temperature F	Yield Strength 0.2% Offset KSI	Tensile Strength KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent
13 Unnotched	750F	198	220	17	8.5	51
14 Notched	"	---	291	--	--	--
15 Notched	"	---	286	---	--	--

$$\text{Average } \frac{\text{Notched}}{\text{Un-notched}} = 1.31$$

FRACTURE TOUGHNESS TEST DATA FOR AMS 6434

Specimen No.	Notch Area	Fracture Load lbs.	Net Stress KSI	G_c psi-in	Yield Strength Level, KSI
1	30%	282,000	166	1520	210
2	30%	270,000	152	1420	190

TABLE VII

CHARPY IMPACT TEST DATA FOR AMS 6434

Heat - 319494

Heat Treatment - Austenitized 1600F, Quenched in Oil and Tempered at 750F to Obtain 200 KSI Yield Strength Level

Specimen No.	Material Description	Energy Absorbed (ft. lbs.)
6	Shell - Long.	19.5
7	Shell - Long.	19.5
10	Shell - Trans.	20.0
11	Shell - Trans.	20.0
16	Shell - Long.	12.0
17	Shell - Long.	15.0
18	Shell - Long.	13.0
19	Shell - Trans.	18.5
20	Shell - Trans.	19.0
21	Shell - Trans.	19.5

TABLE VIII

TENSION TEST DATA FOR D-6-AC
FLAT SPECIMENS

Heat: 9207803

(3/8" x ½" Specimens Austenitized at 1625F, Quenched in Oil and Tempered for 2 hr. as indicated.)

Tempering Temp. F	Yield Strength 0.2% Offset KSI	Tensile Strength KSI	Fracture Strength KSI	Elongation Per Cent		Reduction in Area Per Cent	Hardness R_c
				1"	2"		
600	223	263	293	9.0	6.0	15	50.0
600	224	270	315	14.0	8.0	24	50.0
700	218	254	310	14.0	8.0	28	49.5
700	215	253	294	14.0	8.0	22	50.0
800	213	241	274	14.0	8.0	19	48.0
800	213	239	279	13.0	8.0	20	48.0
900	198	228	277	16.0	11.0	26	45.5
900	199	227	262	14.0	9.0	22	47.0
1000	194	222	284	---	---	32	44.0
1000	196	221	279	17.0	11.0	30	45.0
1100	187	204	269	20	12.0	37	42.0
1100	174	192	272	---	---	42	42.5

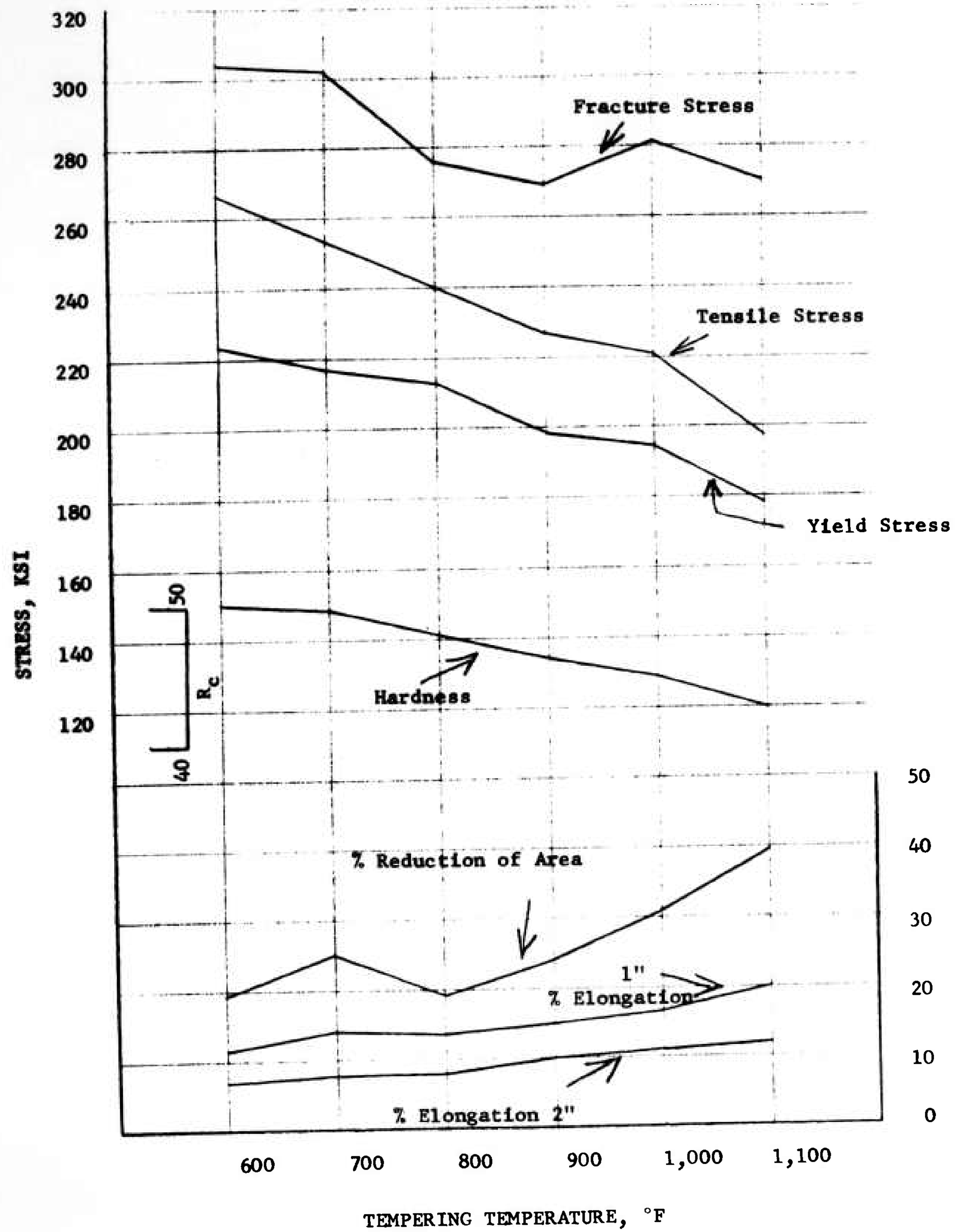


Figure 14. Effect of tempering temperature on the tensile properties of D-6-AC (specimens austenitized 1625F, oil quenched, and tempered for 2 hrs. at temperatures indicated).

TABLE IX

CHARPY IMPACT TEST DATA FOR D-6-AC

Heat - 3950816

Heat Treatment - Austenitized 1625F, Quenched in Oil and Tempered 1000F

Specimen No.	Specimen Direction	Energy Absorbed (ft. lbs.)
1	Trans.	21.0
2	"	22.5
3	"	24.0
4	"	22.0
5	"	22.0
6	"	22.0
7	"	24.0

TABLE X

TENSION TEST DATA FOR D-6-AC ROUND UN-NOTCHED AND NOTCHED SPECIMENS

Heat - 3950816

Heat Treatment - Austenitized 1625F, Quenched in Oil and Tempered 1000F

Specimen No.	Yield Strength 0.2% Offset KSI	Tensile Strength KSI	Fracture Stress KSI	Elongation Per Cent 1"	2"	Reduction in Area Per Cent
8	215	234	328	18	10	47
9	204	230	344	19	10.5	53
10	---	333	---	--	--	--
11	---	315	---	--	--	--

Average $\frac{\text{Notch T.S.}}{\text{Un-notched T.S.}} = 1.40$

TABLE XII

TENSION TEST DATA FOR MARAGING 18 PER CENT NICKEL STEELS

Heat No.	Specimen Size	Specimen Direction	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent
23831	1.0" x 0.375"	L	289	292	20.0	---	45
"	"	T	292	297	18.0	---	48
X-13371	1.0" x 0.500"	L	248	254	18.0	13.0	40
"	"	L	249	256	23.0	13.0	40
"	"	T	245	251	22.0	12.0	41
"	"	T	244	250	20.0	12.0	41
4780-70979	0.5" x 0.500"	L	200	206	18.0	11.5	41
"	"	L	206	211	18.0	10.5	33
"	"	L	202	207	22.0	14.0	45
04524	0.5" x 0.500"	L	246	256	23.0	13.0	42
"	"	L	241	253	23.0	12.5	51
"	"	L	244	255	22.0	12.0	47
"	"	L	241	252	16.0	9.0	30

(a) All Specimens Maraged at 900-925F for 3 Hours

EFFECT OF AGING TEMPERATURE ON TENSILE PROPERTIES OF 200 KSI, 18 PER CENT MARAGING STEEL

Heat 4780-70979

Specimen 0.5" x 0.500" Flats Taken Longitudinally

Aging Temp. F	Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent	Hardness R_c
850	195	199	236	19.0	10.0	35	42.5
"	192	199	236	16.0	8.5	28	42.0
875	198	205	250	19.0	10.0	36	44.0
"	199	204	245	17.0	9.5	33	44.0
900	203	208	239	13.0	6.5	25	44.0
"	202	209	240	15.0	8.5	25	45.0
925	207	210	236	12.0	7.0	22	45.0
"	202	208	226	13.0	7.5	17	45.0
950	194	201	208	12.0	7.0	15	44.0
"	193	198	231	14.0	7.5	20	44.0
975	200	202	224	14.0	8.0	15	44.0
"	202	205	226	15.0	9.0	20	44.0
1000	192	196	225	13.0	9.0	19	43.0
"	195	199	240	18.0	10.5	27	43.0

Specimens size 0.5 x 0.500 taken transversely

TABLE XII (Continued)

975	196	198	247	24.0	14.0	48	--
"	196	200	249	20.0	10.5	41	43.0
900	198	202	245	25.0	13.0	45	45.0
"	195	200	244	21.0	12.0	40	45.0
925	201	205	248	25.0	13.5	44	45.0
"	198	203	237	22.0	12.0	36	43.5
950	197	200	227	22.0	12.5	33	43.0
"	197	199	233	22.0	12.5	35	45.0
975	195	197	234	22.0	13.0	35	42.0
"	196	198	244	24.0	13.0	39	44.0
1000	188	192	250	23.0	14.0	41	--
"	188	191	216	26.0	14.0	33	42.0

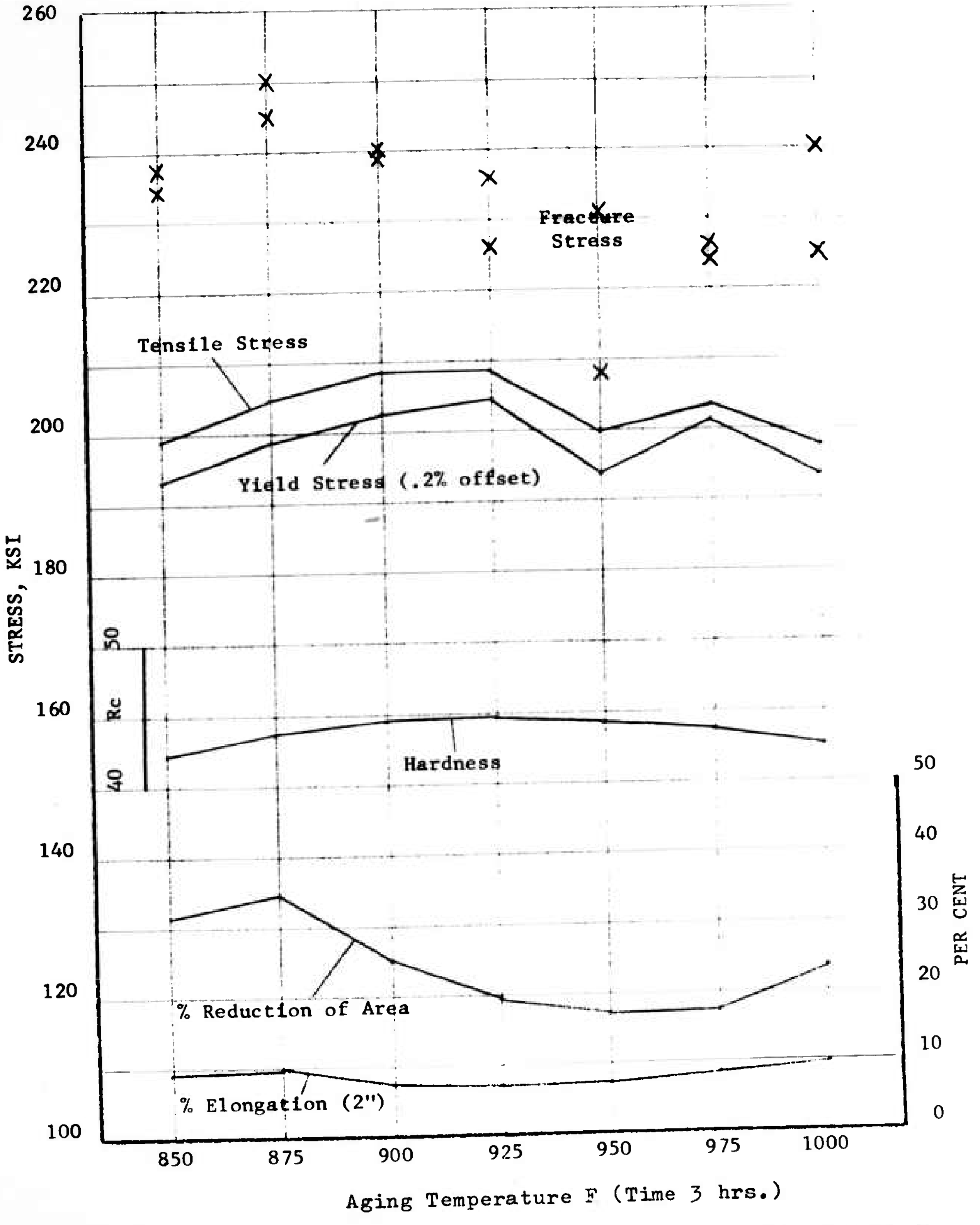


Figure 15. Effect of Aging Temperature on the tensile properties of 200 Ksi Maraging 18 Per Cent Nickel Steel (specimens taken longitudinally). Heat No. 4780-70979

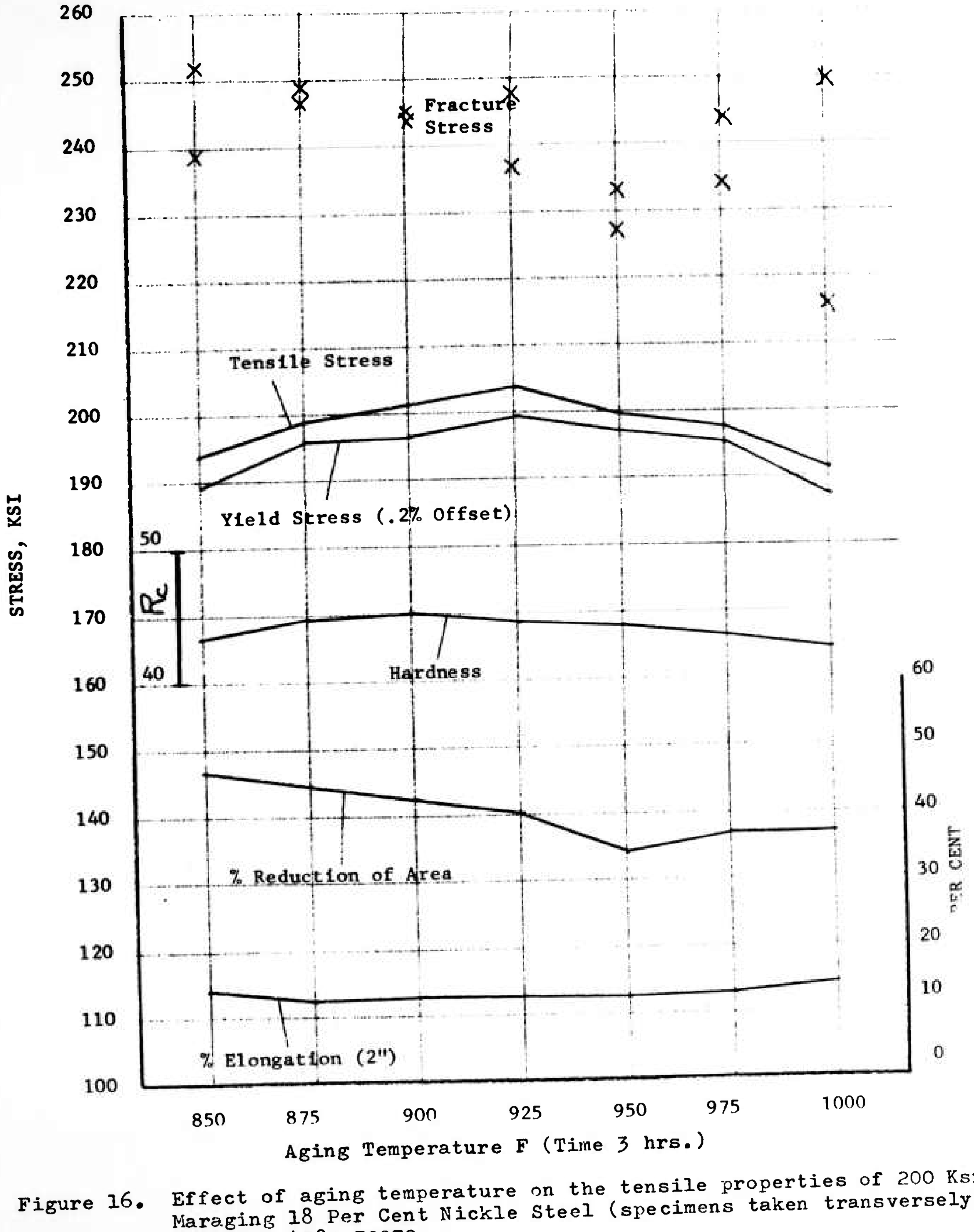


Figure 16. Effect of aging temperature on the tensile properties of 200 Ksi Maraging 18 Per Cent Nickle Steel (specimens taken transversely) Heat No. 4780-70979

TABLE XIII

CHARPY IMPACT TEST DATA FOR MARAGING 18 PER CENT NICKEL STEELS

Heat No. 23831 — 300 KSI Strength Level - Aged at 925F
Subsize (0.320" x 0.320" x 2.17") Specimen - Notch Depth - 0.642"

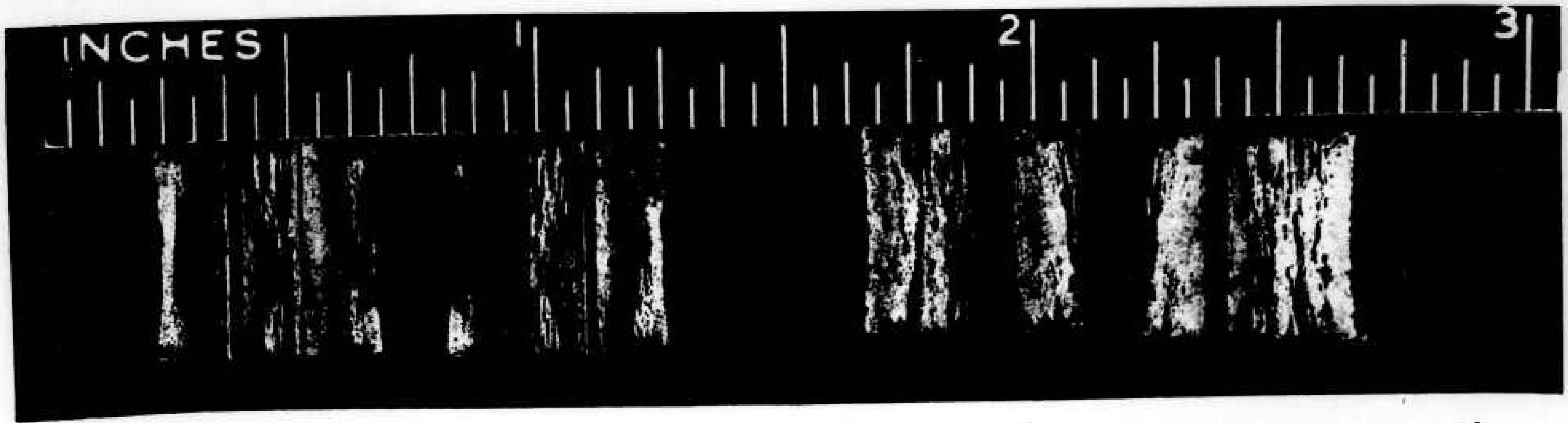
SPECIMEN DIRECTION AND IDENTIFICATION	ENERGY ABSORBED ft. lbs.
Long. 2A	9.5
" 2B	10.5
" 2C	9.0
" 2D	9.5
" 2E	8.5
" 2F	12.0
Trans. 2G	8.5
" 2H	9.0
" 2I	11.5
" 2J	11.0
" 2K	11.5
" 2L	10.0

Heat 23560 — 200 KSI Strength Level - Aged at 925F
Full Size (0.394" x 0.394" x 2.17") Specimens

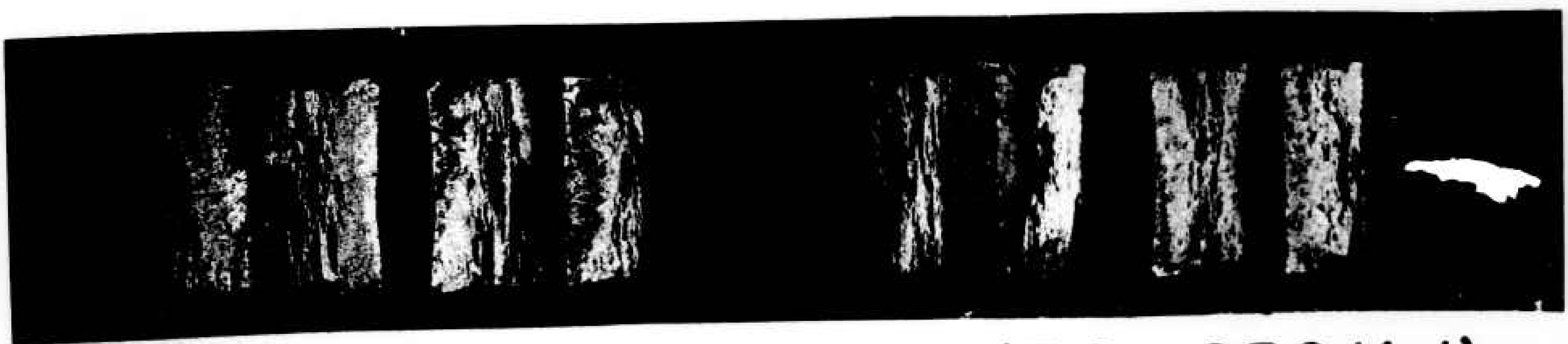
SPECIMEN DIRECTION AND IDENTIFICATION	ENERGY ABSORBED ft. lbs.
Long. 1A	27.0
" 1B	27.0
" 1C	28.0
Trans. 1D	28.0
" 1E	26.0
" 1F	29.0

Heat X-13371 — 250 KSI Strength Level - Aged at 900F
Full Size (0.394" x 0.394" x 2.17") Specimens

SPECIMEN DIRECTION AND IDENTIFICATION	ENERGY ABSORBED ft. lbs.
Long.	18.5
"	18.0
Trans.	15.5
"	16.0

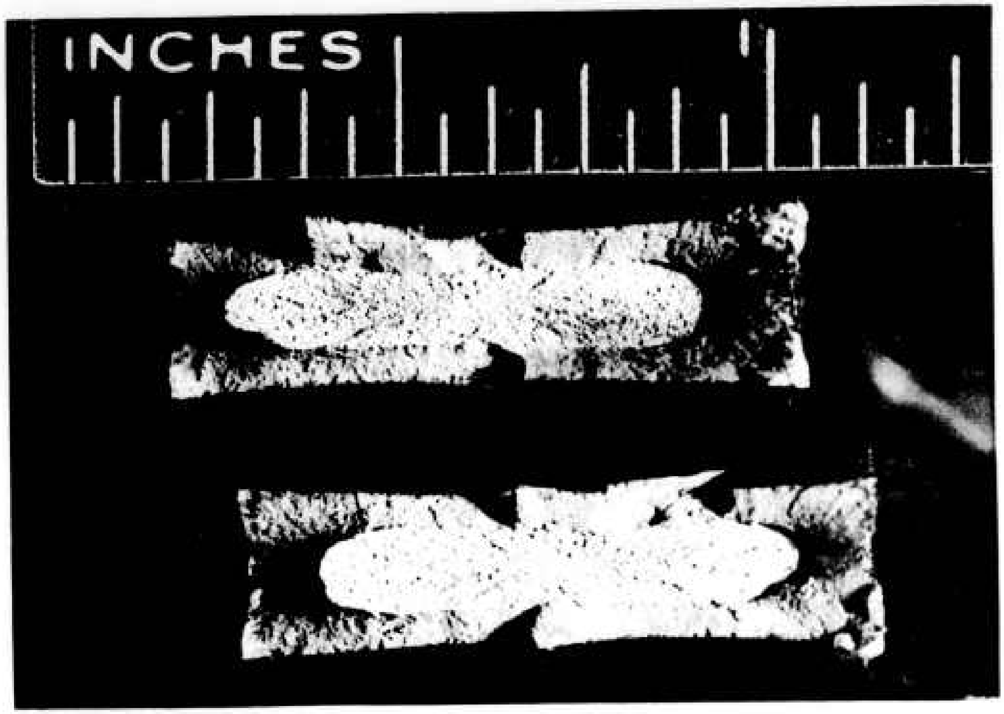


18-1(T.S.=254 Ksi) 18-2(T.S.=256 Ksi)

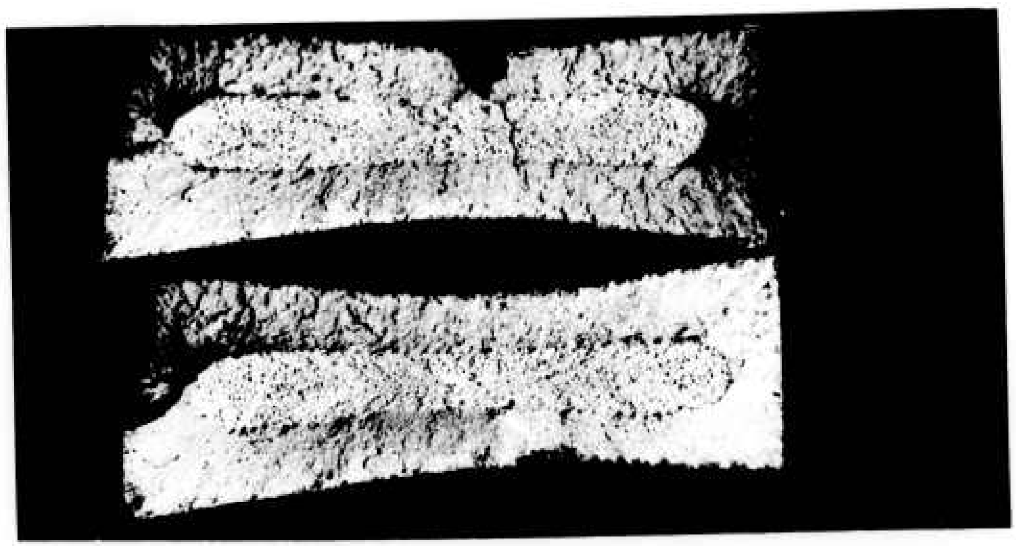


18-3(T.S.=251 Ksi) 18-4(T.S.=250 Ksi)

Figure 17. Fracture appearance and flat tensile specimens of 250 Ksi Maraging 18 Per Cent Nickel Steel (heat X-13371)

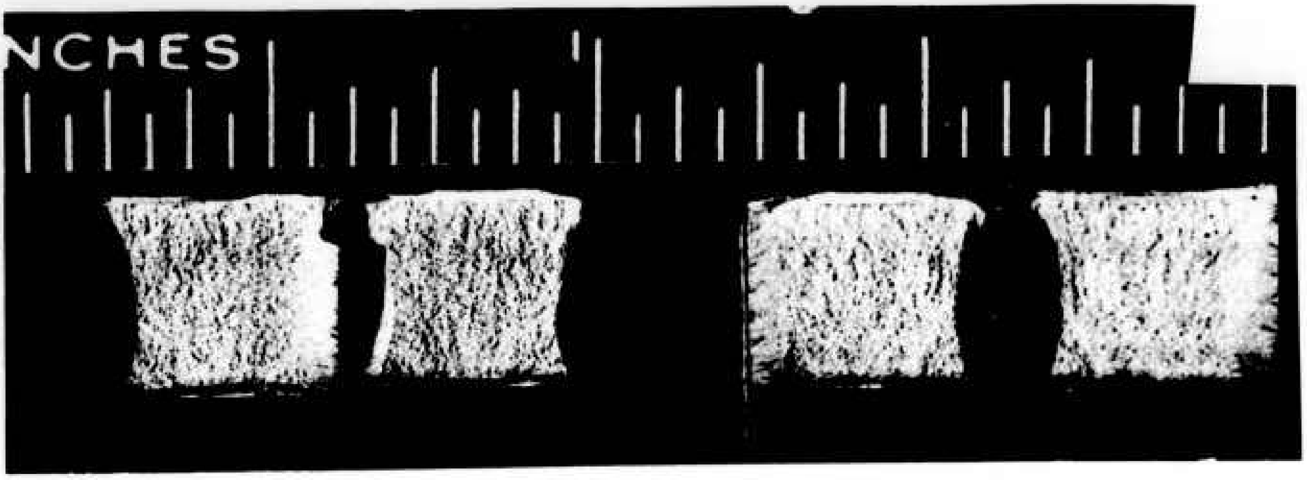


1T(T.S.=297 Ksi)

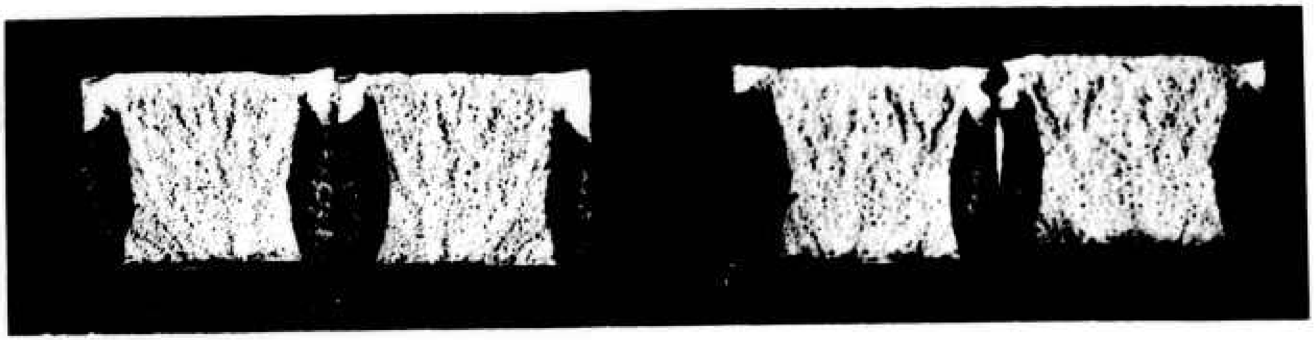


2L(T.S.=292 Ksi)

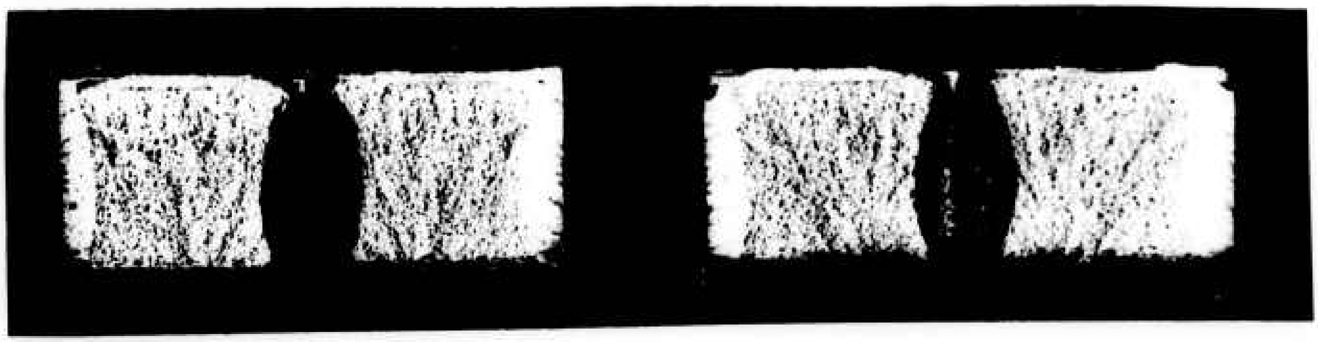
Figure 18. Fracture appearance and extent of necking prior to fracture in flat tension specimens of 300 Ksi Maraging 18 Per Cent Nickel Steel.



1A(27.0 ft. lb.) 1B(27.0 ft. lb.)



1C(28.0 ft. lb.) 1D(28.0 ft. lb.)



1E(26.0 ft. lb.) 1F(29.0 ft. lb.)

Figure 19. Fractures observed in Maraging 18 Per Cent Nickel Steel Charpy Impact Specimens (Heat 23560)

TABLE XIV

FRACTURE TOUGHNESS TEST RESULTS FOR MARAGING 18 PER CENT NICKEL STEELS

Heat No. 23831 - Specimen 1 width 6.00", thickness 0.400"

Heat No. 23560 - Specimens 2 and 3 width 6.00", thickness 0.350"

Specimen No.	Notch Area	Fracture Load lbs.	Net Stress* KSI	G_c (psi-in)	Yield Strength Level, KSI
1	30%	284,000	220	2840	200
2	30%	154,000	144	1170	300
3	40%	134,000	200	1660	300

$$* \text{ Net Stress } = \frac{\text{Load at Fracture}}{(W-2a)\ t}$$

where w=Specimen width
2a=Slow crack growth
t=Specimen thickness

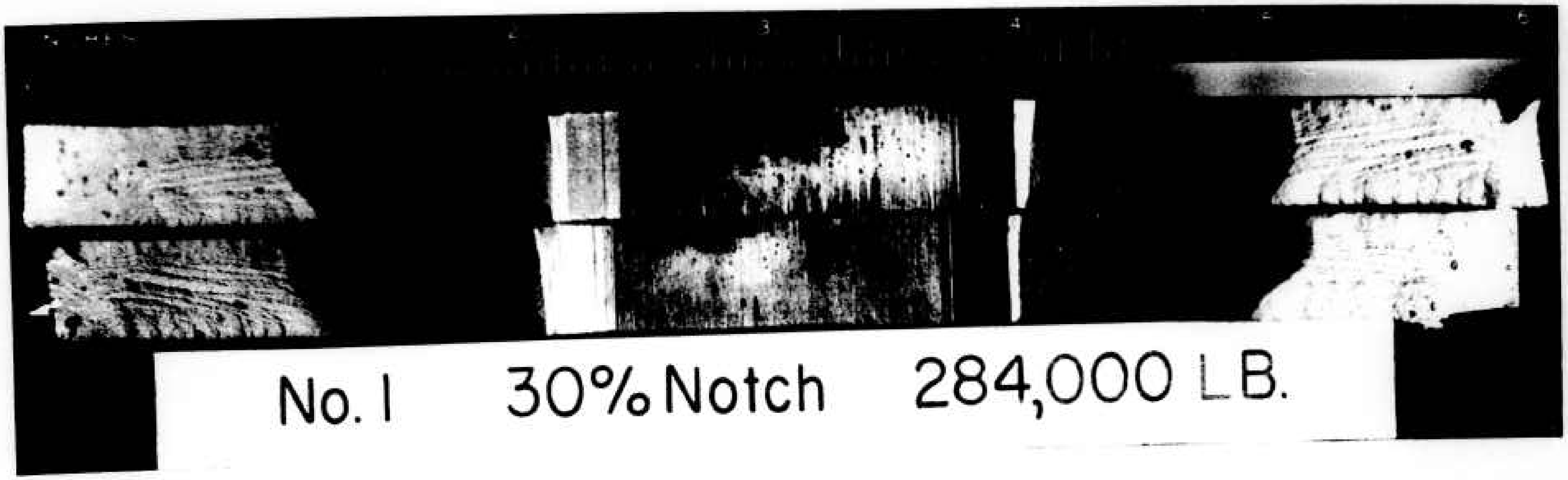


Figure 20. Fracture surface in a 0.400 in. thick, 6 in. wide plate specimen of 200 Ksi Maraging 18 Per Cent Nickel Steel (G_c=2840 psi-in.)

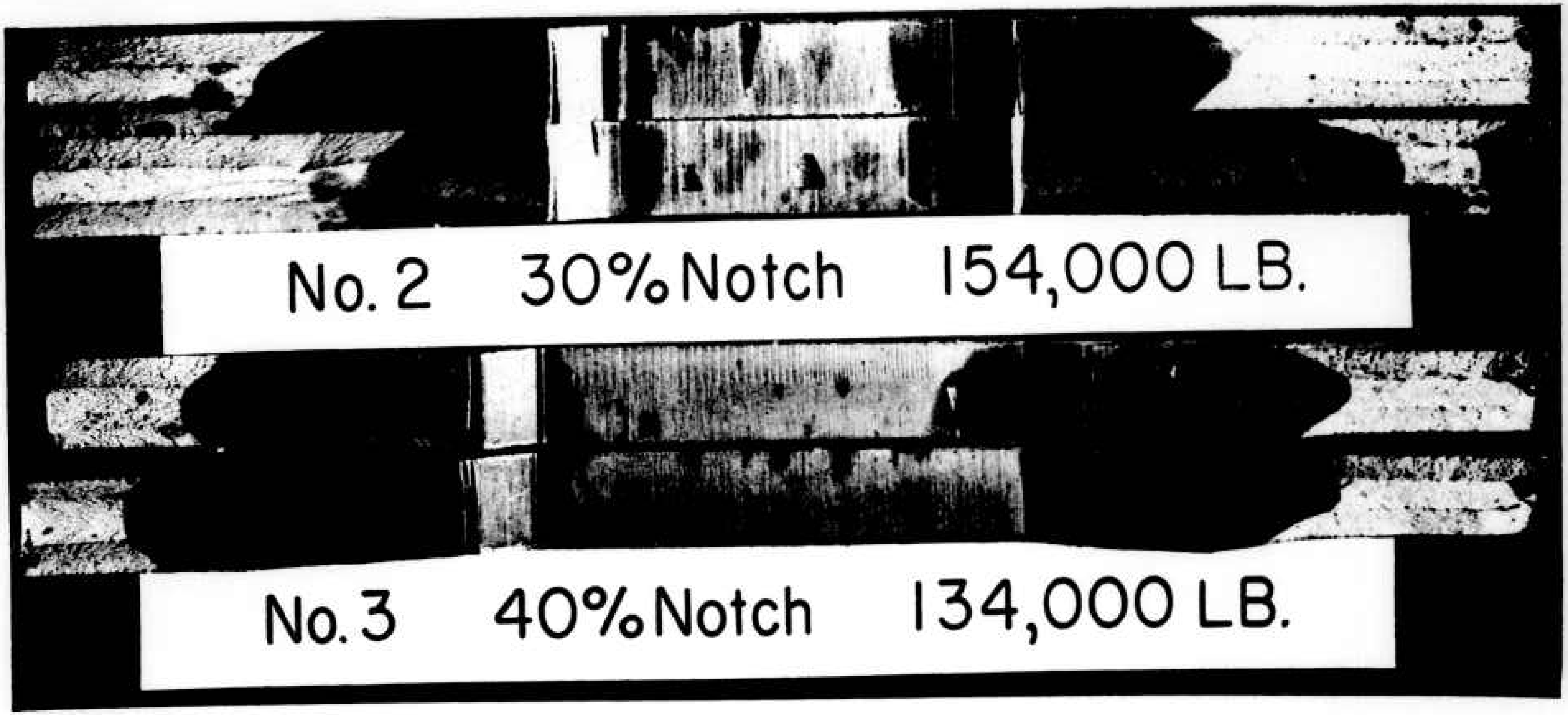


Figure 21. Fracture surfaces in 0.350 in. thick, 6 in. wide plate specimen of 300 Ksi Maraging 18 Per Cent Nickel Steel (G_c=1170 psi-in. No. 2 and G_c=1660 psi-in. No. 3)

EXCELCO DEVELOPMENTS, INC.

EXCELCO DEVELOPMENTS, INC. **WELDING PROCEDURE #**

Date: 8-28-62
Contract No. AF-04(611)-8517
S. O. No. 3291

1.0 SCOPE

This procedure is to be used only for components listed herein and for weld(s) specified in reference 2.0.

2.0 REFERENCE

2.1 Sample 91-6 2.2.1 Pc. # 91-6 to Pc. #
2.2 Drawing No. 2.2.2 Pc. # to Pc. #
2.3 S.O. No. 3291 2.2.3 Pc. # to Pc. #

3.0 WELD REQUIREMENTS

3.1 Type AMS 255 3.4 Passes 6 OUTSIDE
3.2 Size 360 x 24 X 1/2 3.5 Layers 8 INSIDE
3.3 Position HORRIZONTAL 3.6 Layers

4.0 PROCESS

4.1 Heliarc per -AUTOMATIC TIG

4.1.1 Filler metal size— 1/16
4.1.2 Filler metal type— 71-B
4.1.3 Filler metal Spec. #
4.1.4 Current 210-225
4.1.5 E.M.F. 25-28
4.1.6 Cup Size 8
4.1.7 Cup Type CERAMIC
4.1.8 Electrode Size & Type 1/8 1% T

5.0 BASE METAL

5.1
5.2 AMS 255 B

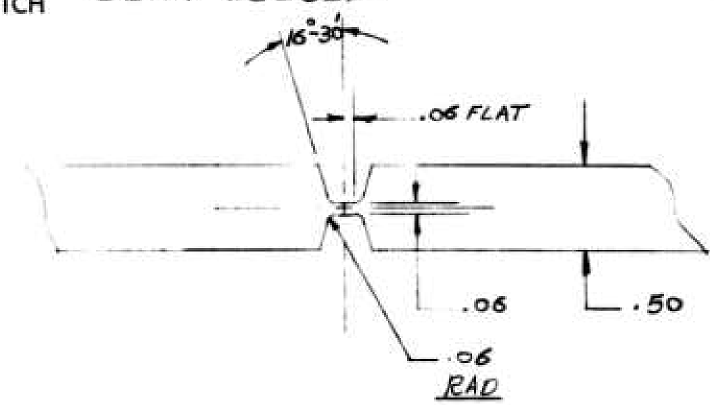
7.0 QUALIFICATIONS

7.1 Procedure per
7.2 Welder(s) per

9.0 REMARKS: PREHEAT 400°F

POSTHEAT NATURAL COOLING IN AIR

8.0 SKETCH SEAM WELDED



4.2 Conditions

4.2.1 Gas Flow 25 TORCH HW-8
4.2.2 Purge YES
4.2.3 Chill Blocks Yes No ✓
4.2.4 Sequence, See Sketch 8.0
4.2.5 Fixture(s) Yes ✓ No
4.2.6 Restrained Yes ✓ No

6.0 INSPECTION

6.1 X-Ray per Spec. MIL-I-6865 MIL-STD-271A
6.2 Dye penetrant per Spec. # MIL-I-6866 A TYPE II
6.3 5X Visual ✓
6.4 Q.C. Witness AS REQUIRED

Prepared by: [illegible] Engineer [illegible] Welder

Approved by: [illegible] Engineering Supervisor

Approved by: M. Pulanski Q. C. Supervisor

Approved by: [illegible] Standards Engineer

Figure 22

TABLE XV

WELD TENSILE TEST RESULTS FOR AMS 6434

Heat - 319494
Specimens - ½" x ½" Section Transverse Weld Tensile Bars
Heat Treatment - Austenitized at 1600F, Quenched in Oil and Tempered as Indicated.

Specimen No.	Tempering Temp. F.	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent	Hardness R_c
12	750	205	219	277	---	9.5	37	44.5

Heat - 13736
Specimens - ½" x ½" Section Transverse Weld Tensile Bars
Heat Treatment - Same as above

Specimen No.	Tempering Temp. F.	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent	Hardness R_c
1	400	152	239	299	---	7.0	28	---
2	400	211	253	281	13.0	7.5	20	---
3	500	211	243	292	16.0	9.0	28	---
4	500	211	241	348	16.0	9.5	32	---
5	600	204	230	381	---	---	35	---
6	600	207	232	321	21.0	12.0	44	---
7	700	194	210	286	---	---	45	---
8	700	193	210	286	---	12.5	44	---
9	800	191	206	264	---	14.0	42	---
10	800	175	191	236	---	---	35	---

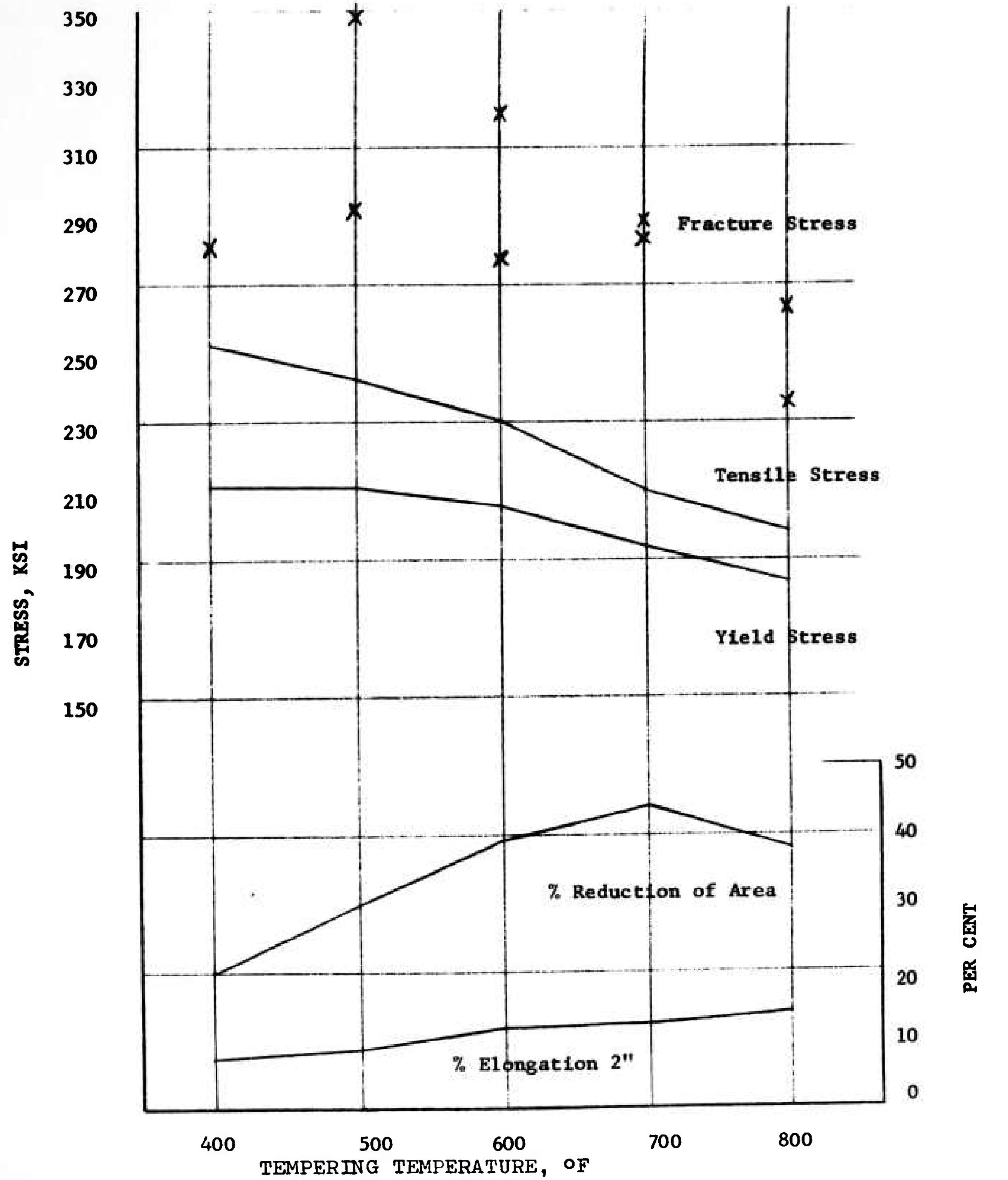


Figure 23. Tensile test data for welded AMS 6434 plate specimens (austenitized 1600F, oil quenched, and tempered as indicated).

TABLE XVI

WELD CHARPY IMPACT TEST DATA FOR AMS 6434

Heat - 319494
Specimen - Located transversely in weld
Heat Treatment - Austenitized 1600F, Quenched in Oil and Tempered at 750F for 200 KSI Yield Strength Level

Specimen No.	Material	Energy Absorbed ft. lbs.
8	Weld Long.	27.0
9	Weld Long.	26.0
A	Weld Trans.	15.0
B	Weld Trans.	19.0

YIELD STRESS VS. MATERIAL THICKNESS

A - .08 THICK - POLARIS

B - .10 THICK - POLARIS

C - .16 THICK - POLARIS

D - .30 THICK - APOLLO

E - .50 THICK - G.C.R.

F - .625 THICK - G.C.R.

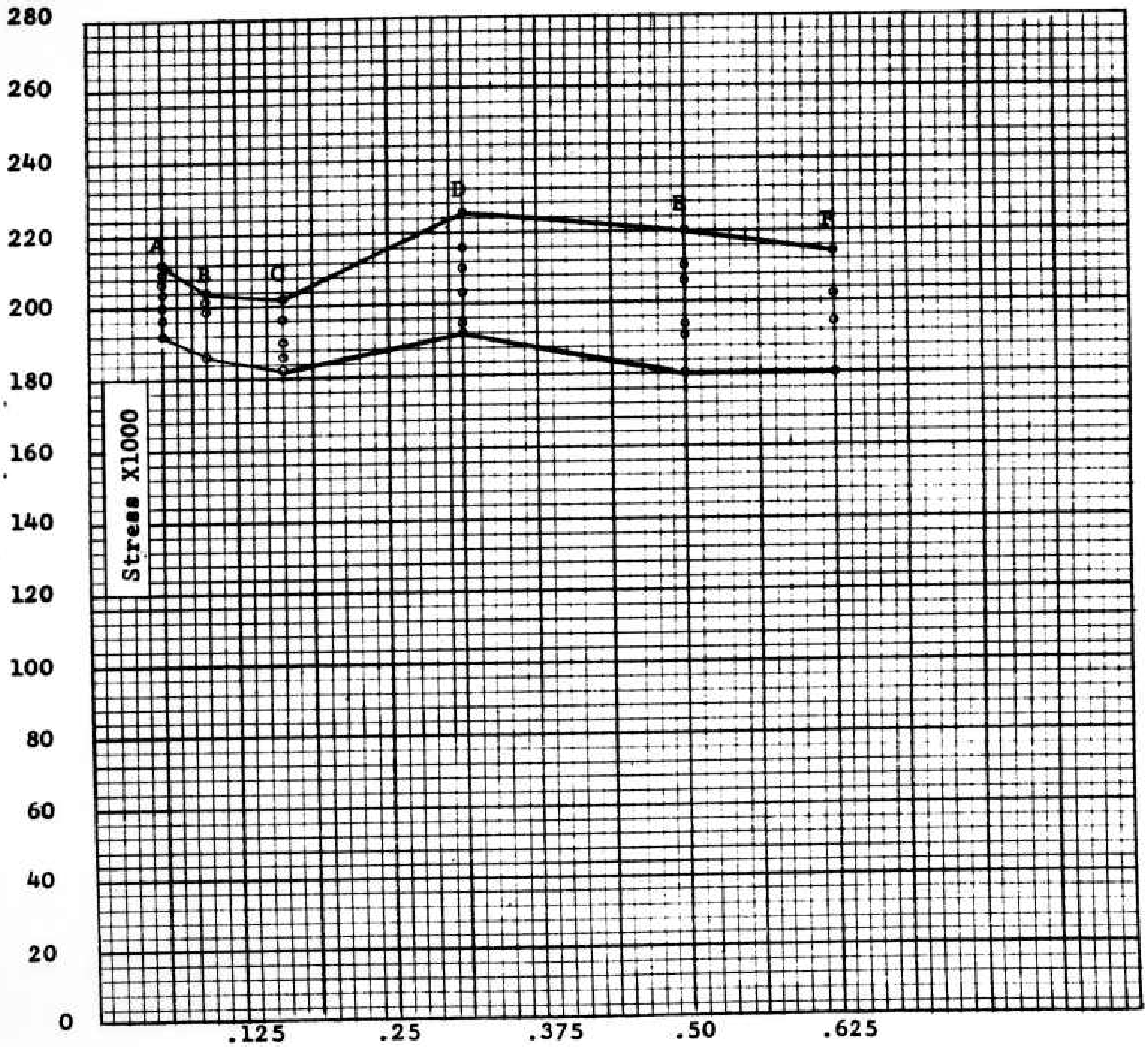


Figure 24

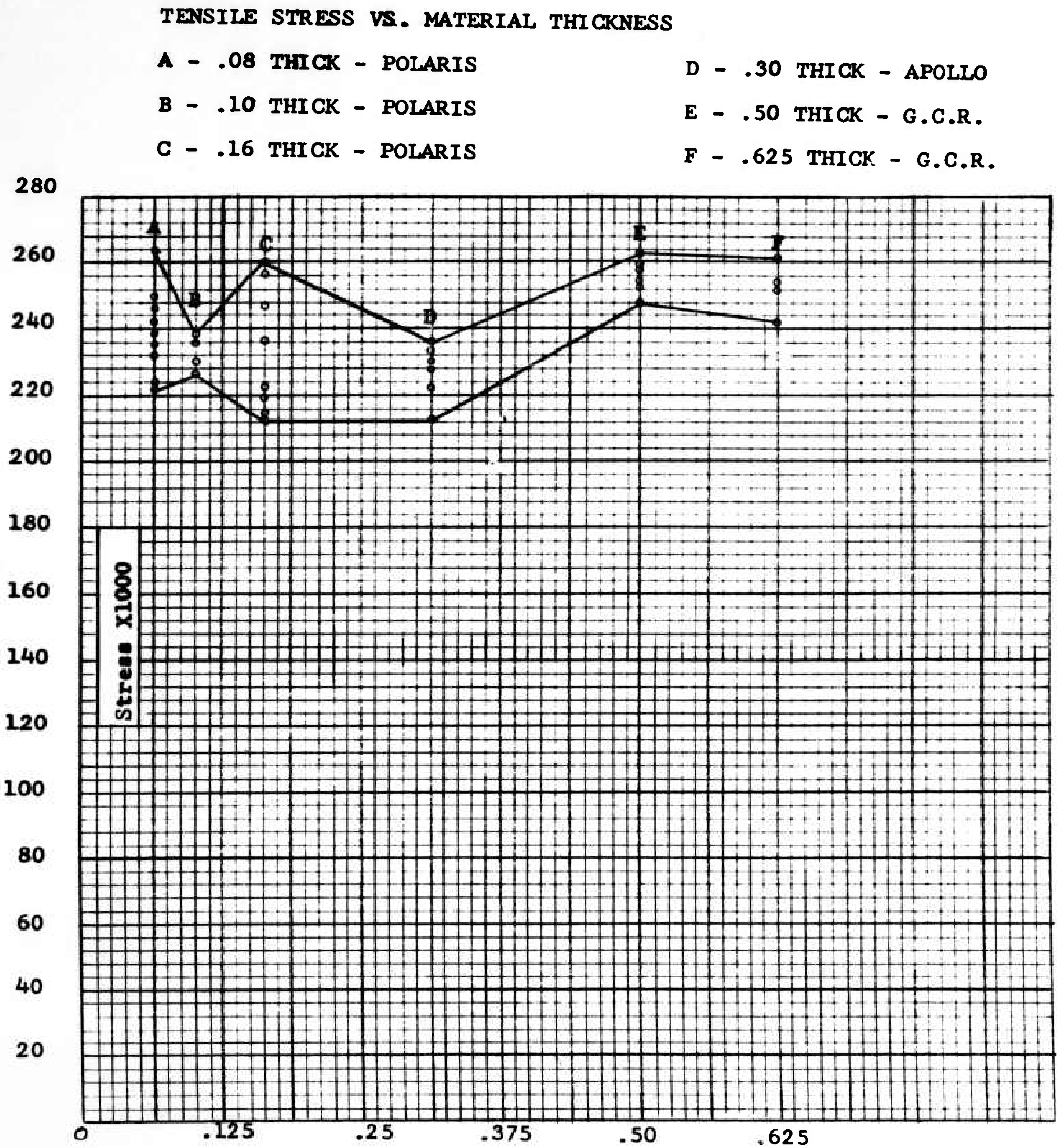

TENSILE STRESS VS. MATERIAL THICKNESS
A - .08 THICK - POLARIS
B - .10 THICK - POLARIS
C - .16 THICK - POLARIS
D - .30 THICK - APOLLO
E - .50 THICK - G.C.R.
F - .625 THICK - G.C.R.
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Stress X1000
0
.125
.25
.375
.50
.625
A
B
C
D
E
F

Figure 25

EXCELCO DEVELOPMENTS, INC.

EXCELCO DEVELOPMENTS, INC. **WELDING PROCEDURE #** ....

Date: 8-21-62
Contract No. AF-04(611)-8517
S. O. No. 3291

1.0 SCOPE

This procedure is to be used only for components listed herein and for weld(s) specified in reference 2.0.

2.0 REFERENCE

2.1 Sample 91-1 .... 2.2.1 Pc. # 91-1.3 to Pc. # 91-1.7
2.2 Drawing No. .... 2.2.2 Pc. # .... to Pc. # ....
2.3 S.O. No. 3291 .... 2.2.3 Pc. # .... to Pc. # ....

3.0 WELD REQUIREMENTS

3.1 Type D6aC .... 3.4 Passes 10
3.2 Size 3/8 x 5 x 6 .... 3.5 Layers 10
3.3 Position HORRIZONTAL .... 3.6 Layers ....

4.0 PROCESS

4.1 Heliarc per HAND TIG

4.1.1 Filler metal size— 1/16
4.1.2 Filler metal type— ARMETCO D6aC
4.1.3 Filler metal Spec. # HEAT 06718
4.1.4 Current 75-85 AMPS
4.1.5 E.M.F. 25-28
4.1.6 Cup Size #7
4.1.7 Cup Type CERAMIC
4.1.8 Electrode Size & Type 1/8 TUNGSTEN-1% TH

5.0 BASE METAL

5.1 D6aC - AL. LVD. HEAT NO. WO506
5.2 ....

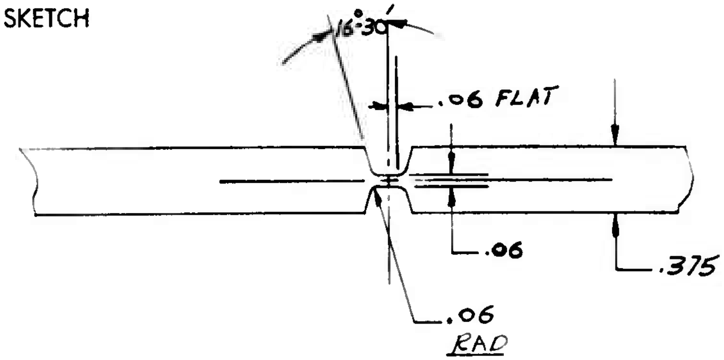
7.0 QUALIFICATIONS

7.1 Procedure per ....
7.2 Welder(s) per MIL-T-5021

9.0 REMARKS:

PREHEAT - 625°F
POST HEAT - FROM 600°F DROP 100°F PER HOUR

8.0 SKETCH



4.2 Conditions

4.2.1 Gas Flow 20 CU. FT./HR. TORCH HW-18
4.2.2 Purge ✓
4.2.3 Chill Blocks Yes .... No ✓
4.2.4 Sequence, See Sketch 8.0
4.2.5 Fixture(s) Yes ✓ .... No ....
4.2.6 Restrained Yes ✓ .... No ....

6.0 INSPECTION

6.1 X-Ray per Spec. MIL-I-6865, MIL-STD-271A
6.2 Dye penetrant per Spec. # MIL-I-6866A TYPE II
6.3 5X Visual ✓
6.4 Q.C. Witness as required

Prepared by: [illegible] (Engineer) [illegible] (Welder)

Approved by: [illegible] (Engineering Supervisor)

Approved by: [illegible] (Q. C. Supervisor)

Approved by: Russell Militello (Standards Engineer)

Figure 26

TABLE XVII

WELD TENSILE TEST RESULTS FOR D-6-AC

Specimens - 1a, 1b, 1c, 1" x .375" Section Transverse Weld Tensile Bars
2, 2^1, 3 - 0.220" Dia. Transverse Weld Tensile Bars

Heat Treatment - Austenitized 1625F, Quenched in Oil and Tempered as Indicated

Specimen No.	Tempering Temp. F	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 2"	Reduction in Area Per Cent
1a	1000F	185	189	257	0.7*	10.2
1b	"	199	206.5	257	3.2*	27.4
1c	"	203	215	260	9.5	26.0
2	"	202	221	356	11.0	47.0
2^1	"	197	216	265	10.0	37.0
3	"	200	216	317	9.0	47.0

Heat No. - X062-9203
Specimens - 3/8" x ½" Section Transverse Weld Tensile Bars

Tempering Temp. F	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Reduction in Area Per Cent
600	237	276	293	7
"	236	271	289	6
700	227	257	272	5
800	225	246	269	14
1000	212	227	287	31
"	210	226	278	28
1100	201	214	286	38
"	203	216	276	32

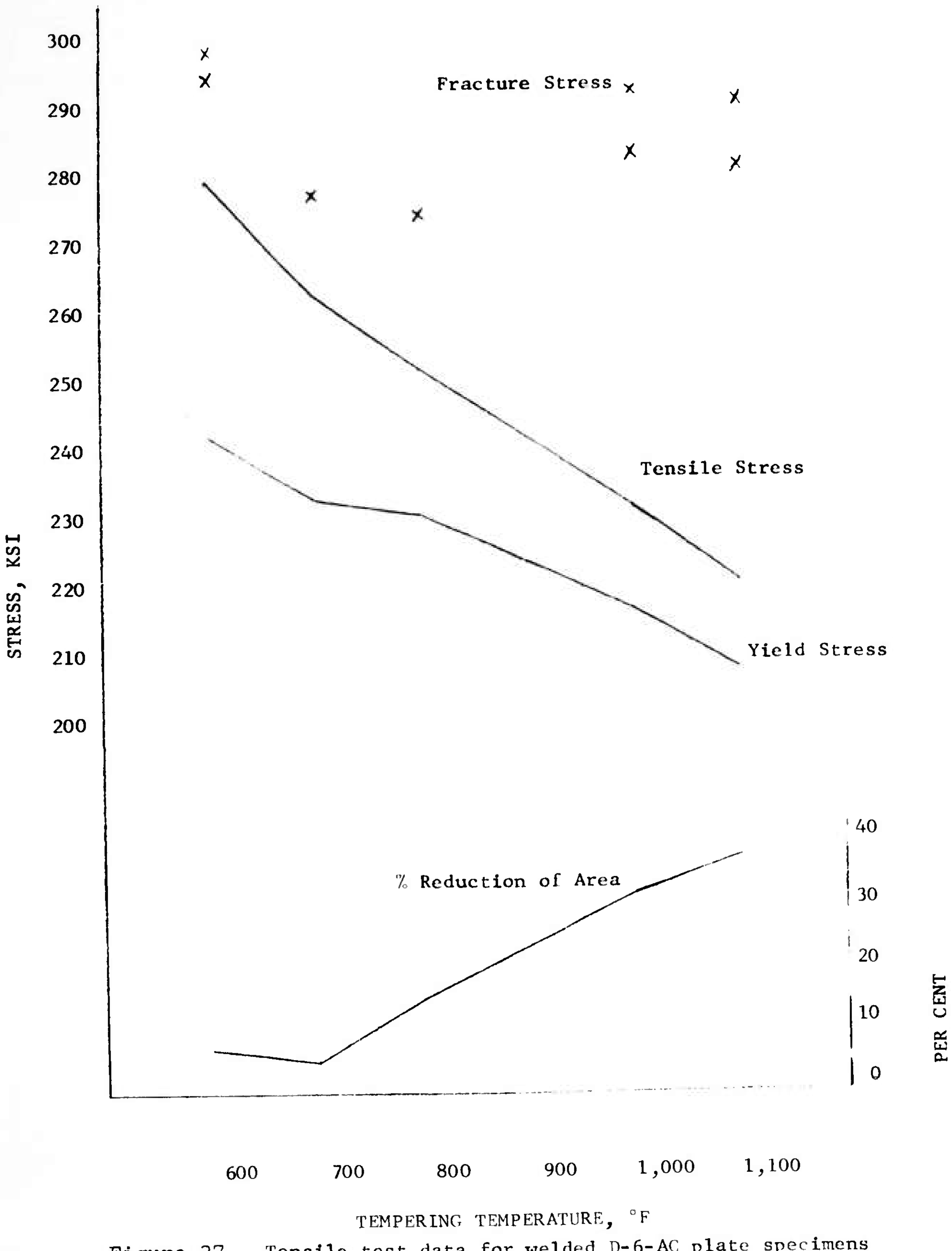


Figure 27. Tensile test data for welded D-6-AC plate specimens (austenitized 1625F, oil quenched, and tempered as indicated).

TABLE XVIII

WELD TENSION TEST DATA FOR D-6-AC AND AMS 6434 ROUND UN-NOTCHED AND NOTCHED SPECIMENS

Heat No.	Specimen No.	Yield Strength 0.2% Offset KSI	Tensile Strength KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent
9207803	2	202	221	356	11.0	---	47
"	2^1	197	216	265	10.0	---	37
"	3	200	216	317	9.0	---	47
"	2a	---x	263	---	---	---	---
"	2b	---x	270	---	---	---	---
"	2^1a	---x	266	---	---	---	---
"	2^1b	---x	273	---	---	---	---
"	3a	---x	266	---	---	---	---
"	3b	---x	270	---	---	---	---

Average $\frac{\text{Notched}}{\text{Unnotched}} = 1.23$

AMS 6434

Heat No.	Specimen No.	Yield Strength 0.2% Offset KSI	Tensile Strength KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent
319494	3	199	216	293	12	6.5	40
"	4	---x	279	---	--	---	--
"	5	---x	290	---	--	---	--

Average $\frac{\text{Notched}}{\text{Unnotched}} = 1.31$

x Data lacking because of continual breaking of expensive strain gauge equipment.

EXCELCO DEVELOPMENTS, INC.

EXCELCO DEVELOPMENTS, INC. **WELDING PROCEDURE #**

Date: 10-19-62
Contract No. AF-04(611)8517
S. O. No. 3291

1.0 SCOPE

This procedure is to be used only for components listed herein and for weld(s) specified in reference 2.0.

2.0 REFERENCE D-1 -2

2.1 Sample -3 2.2.1 Pc. # to Pc. #
2.2 Drawing No. 2.2.2 Pc. # to Pc. #
2.3 S.O. No. 3291 2.2.3 Pc. # to Pc. #

3.0 WELD REQUIREMENTS

3.1 Type MARAGING 18% 3.4 Passes 7 OUTSIDE
3.2 Size 8X6X1/2 3.5 Layers 7 INSIDE
3.3 Position HORRIZONTAL 3.6 Layers

4.0 PROCESS

4.1 Heliarc per HAND TIG.

4.1.1 Filler metal size— .045
4.1.2 Filler metal type— MARAGING
4.1.3 Filler metal Spec. # 13371
4.1.4 Current 125-135
4.1.5 E.M.F. 25-28
4.1.6 Cup Size
4.1.7 Cup Type CERAMIC
4.1.8 Electrode Size & Type 1/8 1% T

5.0 BASE METAL

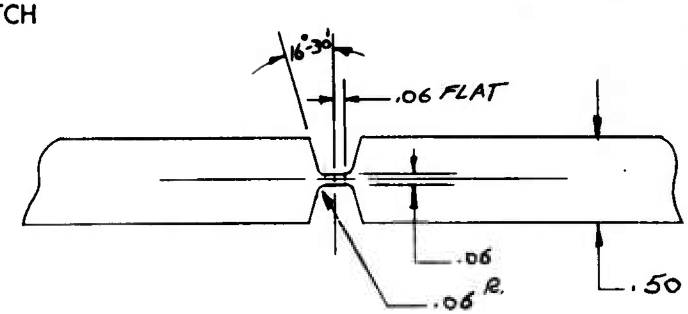
5.1
5.2 MARAGING 18% NI. U.S. STEEL

7.0 QUALIFICATIONS

7.1 Procedure per
7.2 Welder(s) per MIL-I-5021

9.0 REMARKS: PREHEAT NO
POSTHEAT NO

8.0 SKETCH



4.2 Conditions

4.2.1 Gas Flow 35 TORCH HW-18
4.2.2 Purge YES
4.2.3 Chill Blocks Yes No ✓
4.2.4 Sequence, See Sketch 8.0
4.2.5 Fixture(s) Yes ✓ No
4.2.6 Restrained Yes ✓ No

6.0 INSPECTION

6.1 X-Ray per Spec. MIL-I-6865 MIL-STD.-271A
6.2 Dye penetrant per Spec. # MIL-I-6866 A TYPE II
6.3 5X Visual ✓
6.4 Q.C. Witness AS REQUIRED

Prepared by: R. Mwinney Engineer — Welder
Approved by: W. Rbett Engineering Supervisor
Approved by: M. Pilawski Q. C. Supervisor
Approved by: G. Militello Standards Engineer

Figure 28

TABLE XIX

WELD TENSILE TEST RESULTS FOR MARAGING 18 PER CENT NICKEL STEELS

Heat - X-13371

Specimens - 3-3, 3-4, 4-3, 16-1, 16-2, 16-3, Butt Welded ½ plate to ½" plate - transverse weld ½" x ½" section tension specimens. 9-3, 9-4, 10-3, 10-4, 13-3, 13-4, 14-3 and 14-4 - ½" plate welded to 1½" ring - transverse weld ½" x ½" section tension specimens.

Specimen Identification	Aging Treatment	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	2"	Reduction in Area Per Cent
3-3	900F 3 hrs. & 920F 3 hrs.	x	238	267	10.0	5.0	16.5
3-4	900F 3 hrs. & 920F 3 hrs.	x	241	268	9.0	4.5	12.0
4-3	900F 3 hrs. & 920F 3 hrs.	x	242	264	7.0	4.0	9.5
4-4	900F 3 hrs. & 920F 3 hrs.	x	244	263	6.5	4.0	7.0
16-1	900F 3 hrs.	x	248	262	8.0	4.0	6.5
16-2	900F 3 hrs.	x	245	273	12.5	8.0	18.0
16-3	900F 3 hrs.	x	251	251	12.0	6.0	9.5
9-3	900F 3 hrs.	x	235	254	10.0	5.0	13.0
9-4	900F 3 hrs.	x	236	257	8.5	4.0	13.0
10-3	900F 4 hrs.	x	246	263	11.5	6.0	14.0
10-4	900F 4 hrs.	x	248	261	7.5	4.0	7.0
13-3	1000F 3 hrs.	x	245	284	13.0	7.0	17.0
13-4	1000F 3 hrs.	x	225	247	7.5	4.0	9.0
14-3	1000F 4 hrs.	x	227	256	10.0	5.0	11.0
14-4	1000F 4 hrs.	x	232	254	8.0	4.0	8.5

Heat - 120D163
Specimens - ½" x ½" Section Transverse Weld Tensile Bars
Aging Treatment - Welded and Aged at 900F, 4 hrs.

Specimen No.	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	2"	Reduction in Area Per Cent	Hardness R_c
1	248	255	295	14.0	7.0	26.0	49.0
2	248	255	272	9.0	4.0	12.0	49.0
3	250	260	275	5.0	3.5	8.0	49.0
4	244	255	285	11.0	5.5	11.0	49.0

x - Data lacking because of continual breakding of expensive strain gauge equipment.

TABLE XIX (Continued)

Heat - 4780-70979
Specimens - ½" x ½" Section Transverse Weld Tensile Bars
Aging Treatment - Welded and Aged at 925F, 4 hrs.
Filler Wire - Heat 06919 (Armetco)

Specimen No.	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent	Hardness R_c
1	163	202	239	---	7.0	24.0	44.0
2	197	203	225	---	4.0	10.0	44.0
3	199	205	236	---	5.0	17.0	47.0

Heat - X-13371
Specimens - ½" x ½" Section Transverse Weld Tensile Bars
Tests run to study strength of locally aged welds.

Specimen No.	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent	Hardness R_c
11-1	164	210	228	10.0	5.5	15	---
11-2	182	219	247	9.0	5.0	15	---
11-3	179	208	---	9.0	5.0	15.0	---
11-4	172	215	240	9.0	5.0	16.0	---

Heat - 04524
Specimens - ½" x ½" Section Transverse Weld Tensile Bars
Aging Treatment - Welded Specimens 1, 2, 3, and 4 aged at 925F, 4 hrs.
Specimens A1, A2, A3, and A4 aged at 925F, 3 hrs.

Specimen No.	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 1"	Elongation Per Cent 2"	Reduction in Area Per Cent	Hardness R_c
1	231	232	236	5.0	2.5	1.5	---
2	236	240	278	19.0	10.0	29.0	---
3	233	237	265	13.0	7.0	19.0	---
4	231	237	246	3.0	1.5	3.8	---
A1	241	244	273	15.0	7.5	29.0	---
A2	239	241	306	16.0	8.0	39.0	---
A3	239	243	259	18.0	9.0	30.0	---
A4	240	243	276	19.0	9.5	34.0	---

EFFECT OF AGING TEMPERATURE ON WELD TENSILE PROPERTIES OF 200 KSI, 18 PER CENT MARAGING STEEL

Heat - 4780-70979
Specimen - 0.5" x 0.500" Section Transverse Weld Tensile Bar

Aging Temp. F	Yield Stress 0.2% Offset KSI	Tensile Stress KSI	Fracture Stress KSI	Elongation Per Cent 2"	Reduction in Area Per Cent
850	191	191	243	9.0	37
"	183	189	262	10.5	47
875	182	188	247	9.5	40
"	181	188	280	9.5	48
900	183	189	233	8.5	35
"	182	187	244	8.5	38
925	179	185	251	8.0	40

TABLE XIX (Continued)

925	182	186	241	8.5	36
950	179	187	257	10.0	41
"	171	183	252	11.5	44
975	172	182	240	9.5	40
"	174	178	224	11.0	35
1000	192	196	286	9.0	45
"	191	197	293	11.5	48

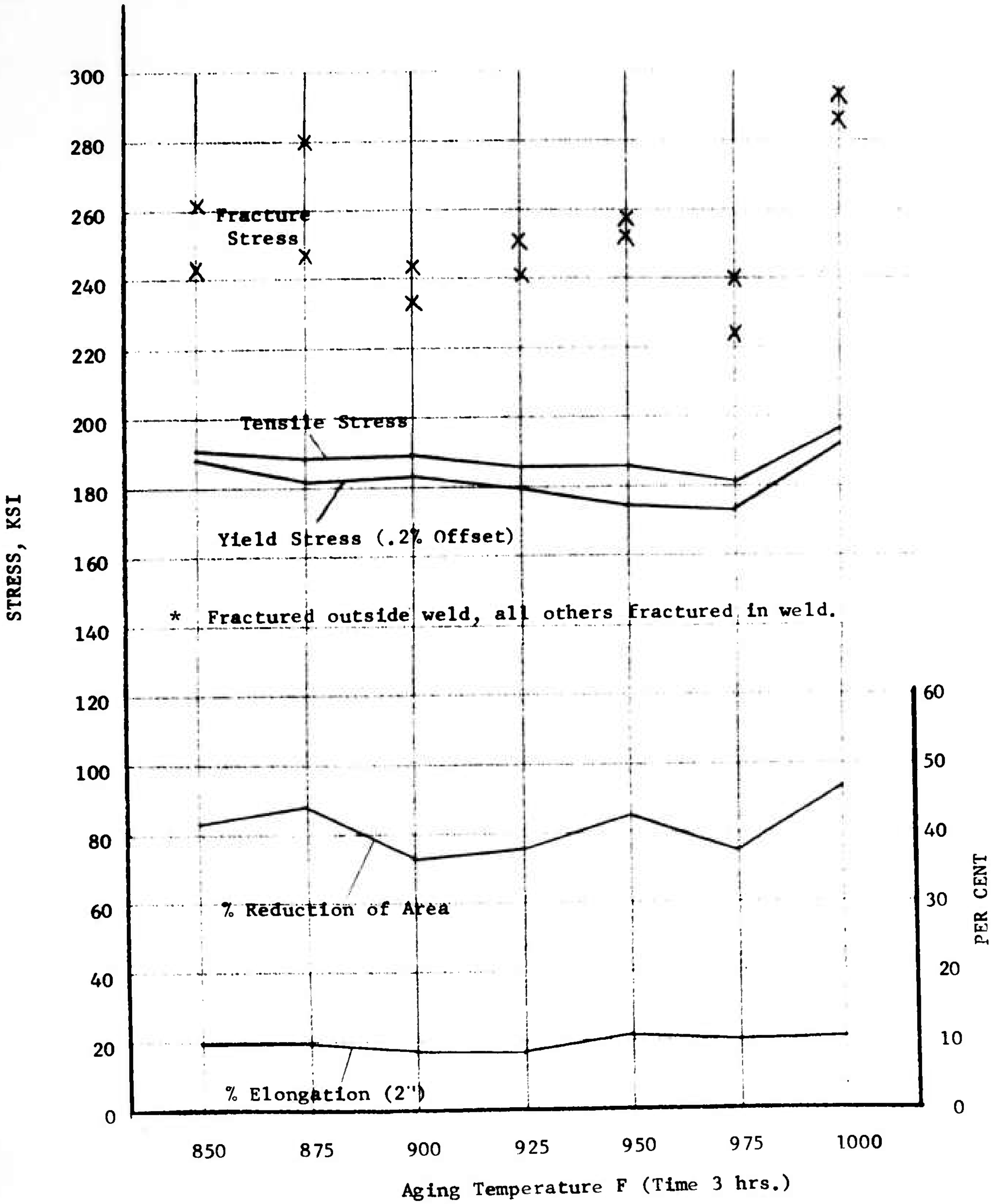


Figure 29. Tensile properties of transversely welded 200 Ksi Maraging 18 Per Cent Nickel Steel aged at various temperatures.

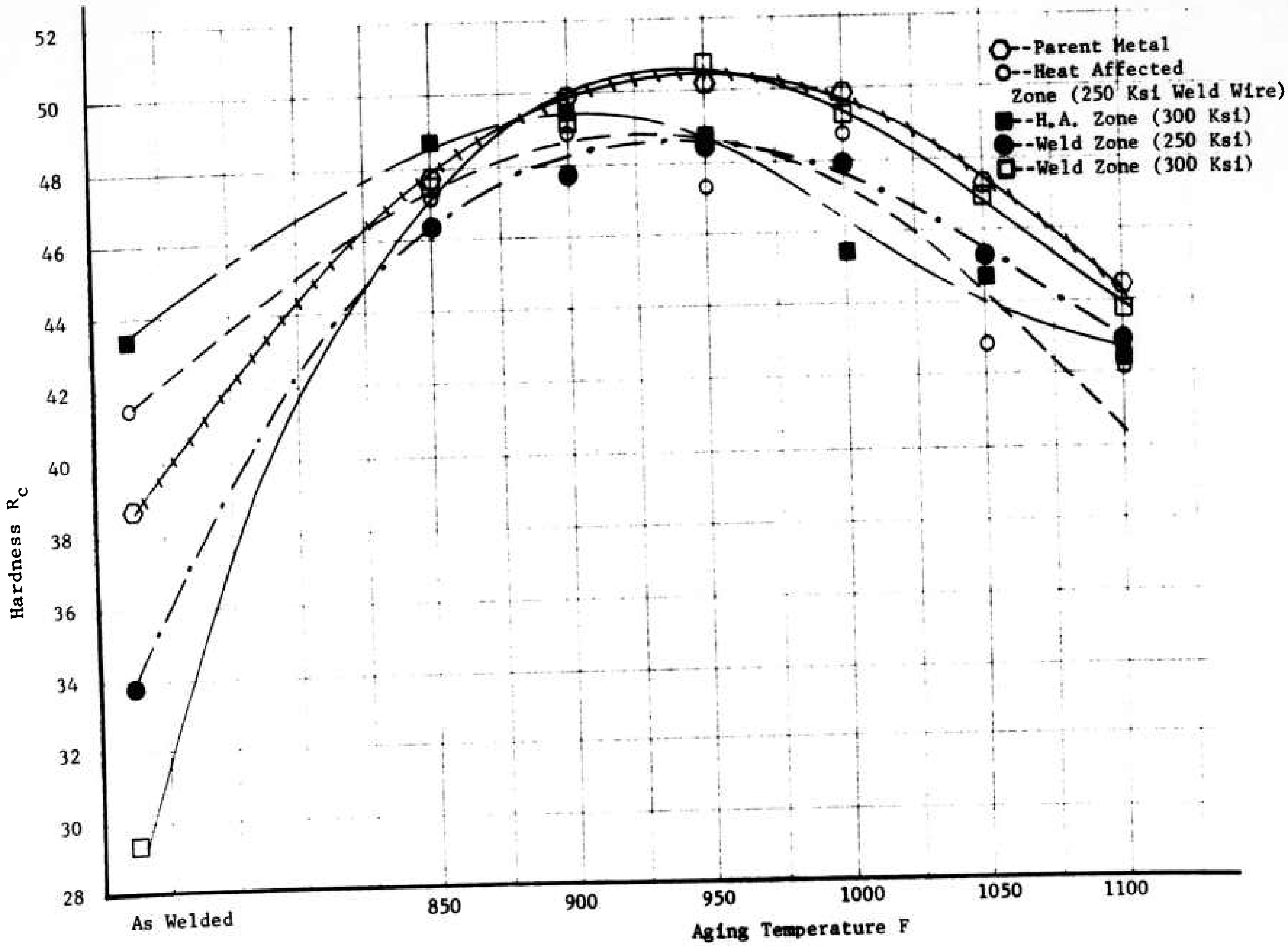


Figure 30. A Hardness Survey of Weldments of 250 Ksi Maraging Steel Welded with 250 Ksi and 300 Ksi Filler Wire

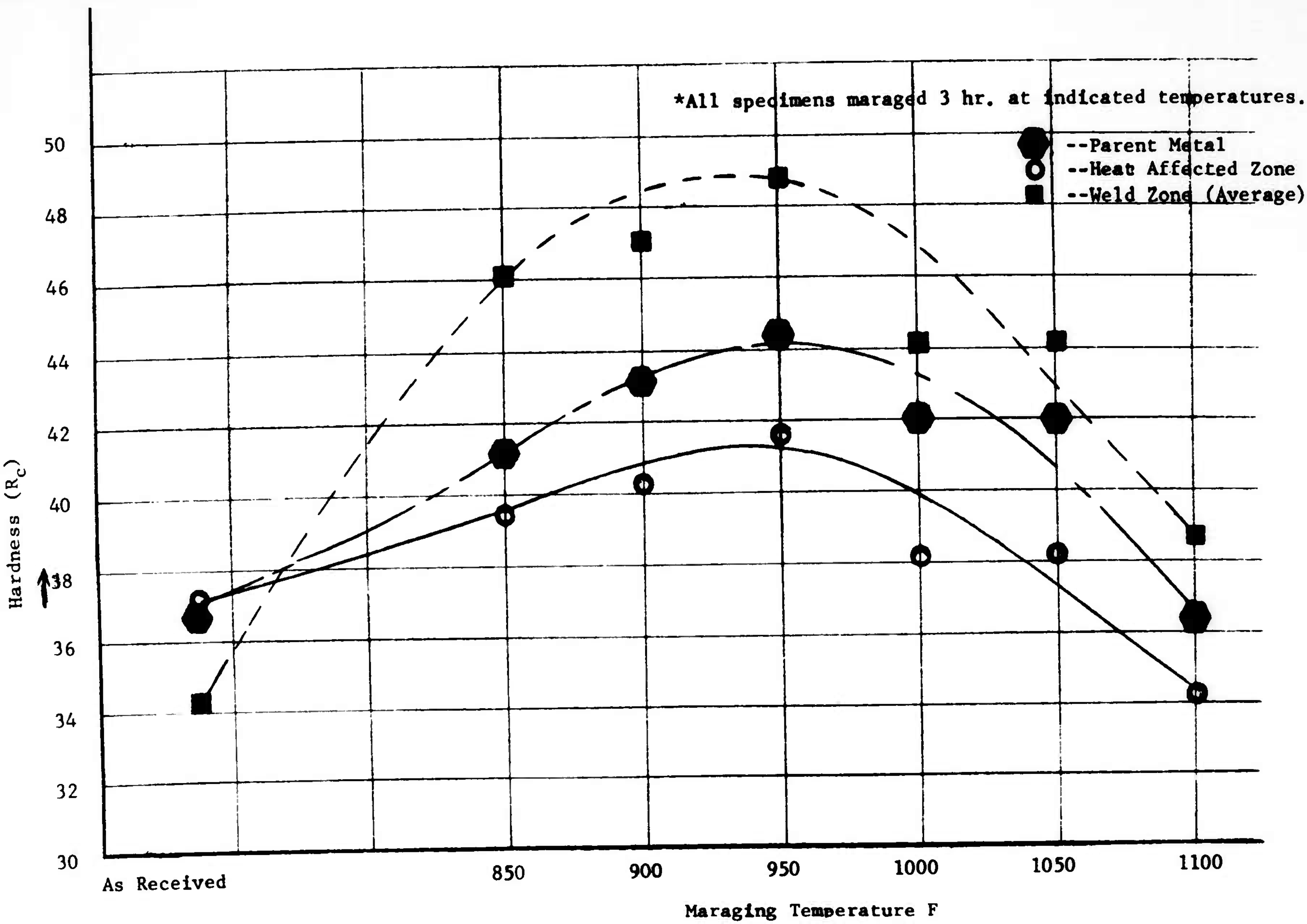


Figure 31. A Hardness Survey of Weldments of a 200 KSI MARAGING STEEL WELDED WITH 240 KSI Filler Wire.

TABLE XX

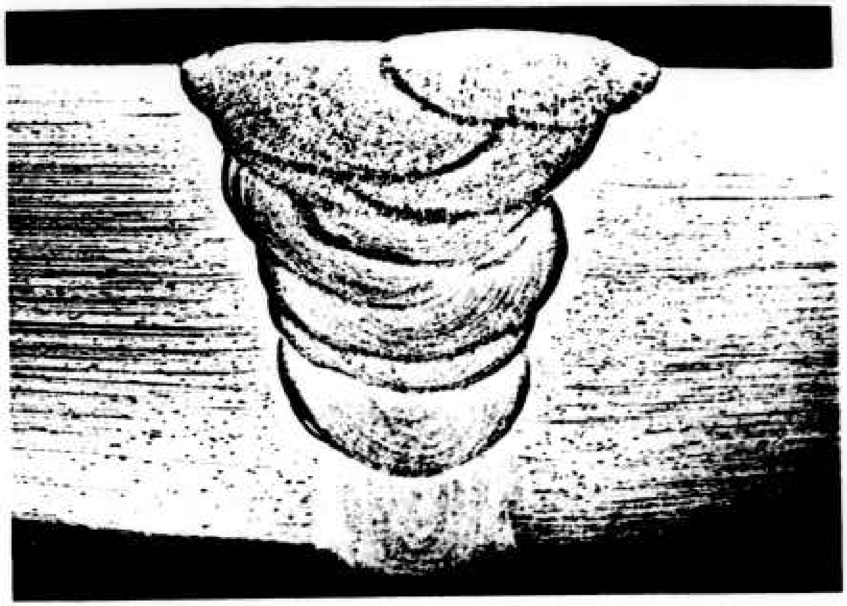
FRACTURE TOUGHNESS TEST RESULTS FOR WELDED MARAGING 18 PER CENT NICKEL STEELS, D-6-AC and AMS 6434 PLATES

Material	Heat No.	Specimen Dimensions	Yield Strength Level KSI	Fracture Load lbs.	Net Stress KSI	G_c psi-in.
Maraging Steel 1 (a)	4780-70979	½"t x 8"w x 24"l	200	148,500	75(b)	392
2 (a)				146,000	58(c)	246
3 (a)				194,500	69(d)	368
4 (e)	120D163	½"t x 8"w x 36"l	250	251,000	150(d)	1530
5 (e)	"	"	250	268,000	156(d)	1650
D-6-AC (816)	3950816	3/4"t x 12"w x 36"l	200	654,000	190	2900
1	9207803	3/8"t x 5"w x 24"l	200	109,000	142(c)	924
2	"		200	135,000	160(d)	1010
3	"	"	200	110,000	152(c)	816
4	"	"	200	93,000	193.5(c)	1040
AMS 6434	319494	½"t x 7½"w x 30"l	200	271,000	168	1500
"	"	"	"	277,500	149	1280

(a) Welded with high titanium (0.65% Ti) content 18 per cent maraging steel filler wire.

(b) - 44% notch; (c) - 40% notch; (d) - 30% notch

(e) - Data from another study. Notch root radius - 0.002 inches.



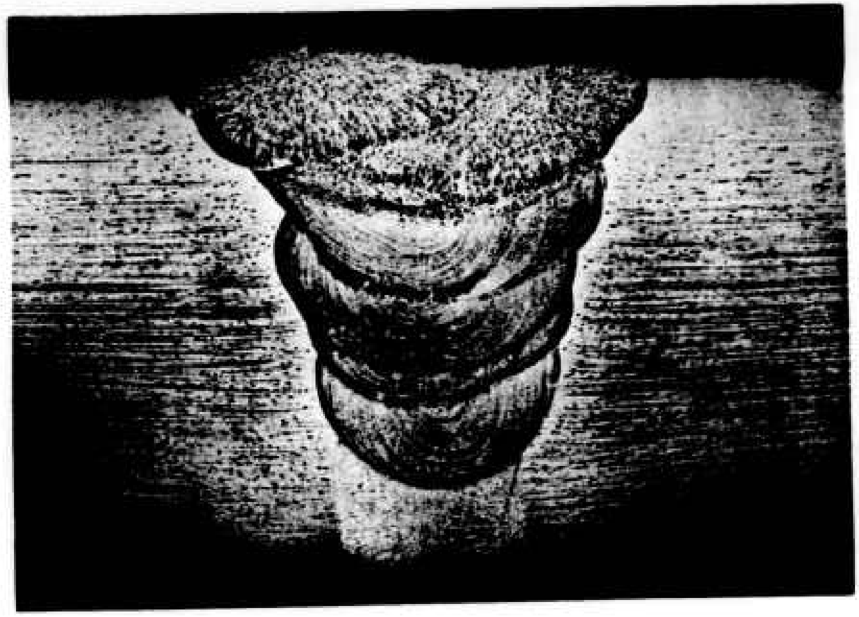
Weld Macrograph (5X)

Parent Metal (1000X)

H. A. Zone (1000X)

Weld Zone (1000X)

Figure 32. Metallographic Study of AMS 6434 Weldment - As Quenched from 1600F



Weld Macrograph (5X)

Parent Metal (1000X)

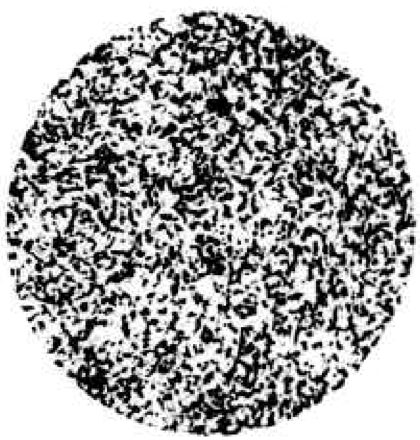
H. A. Zone(1000X)

Weld Zone (1000X)

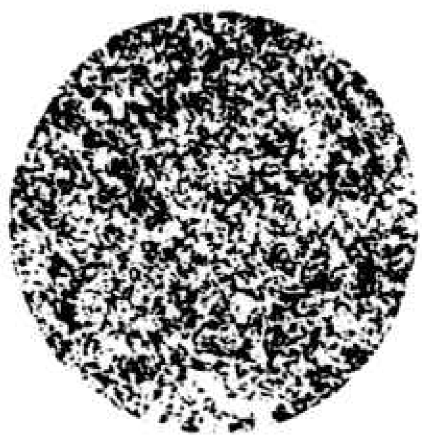
Figure 33. Metallographic Study of AMS 6434 Weldment - Quenched and Tempered at 400F - 2 hrs.

Weld Macrograph (5X)

Parent Metal (1000X)



H. A. Zone (1000X)



Weld Zone (1000X)

Figure 34. Metallographic Study of AMS 6434 Weldment - Quenched and Tempered at 500F - 2 hrs.

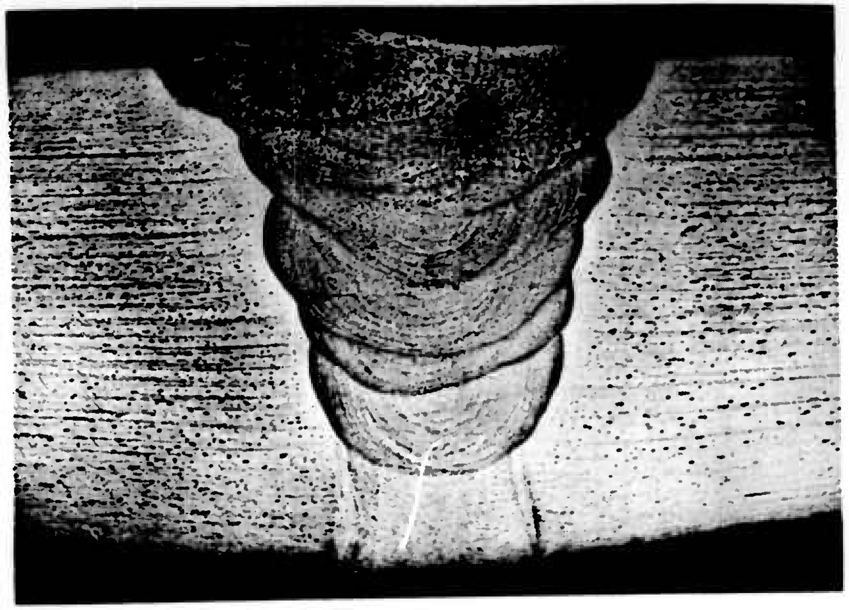
Weld Macrograph (5X)

Parent Metal (1000X)

H. A. Zone (1000F)

Weld Zone (1000X)

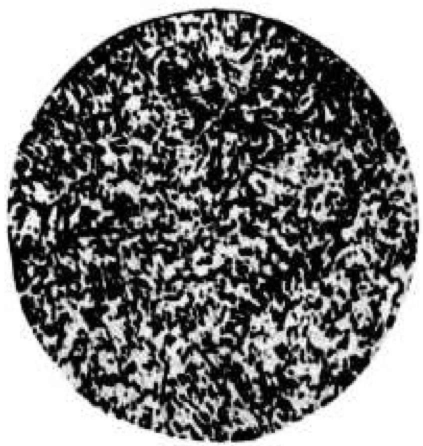
Figure 35. Metallographic Study of AMS 6434 Weldment - Quenched and Tempered at 600F - 2 hrs.



Weld Macrograph (5X)

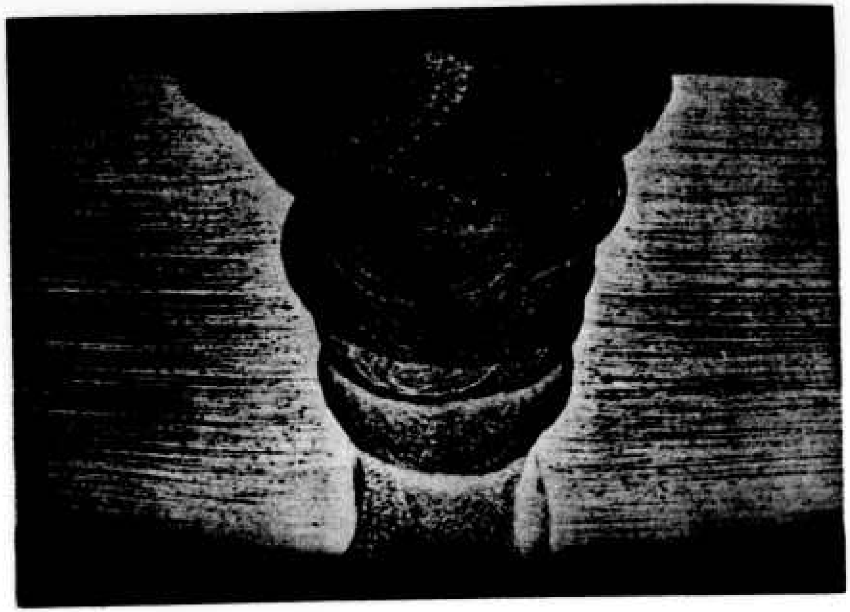
Parent Metal (1000X)

H. A. Zone (1000X)



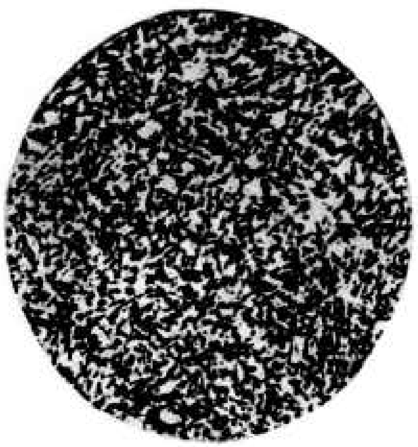
Weld Zone (1000X)

Figure 36. Metallographic Study of AMS 6434 Weldment - Quenched and Tempered at 700F - 2 hrs.



Weld Macrograph (5X)

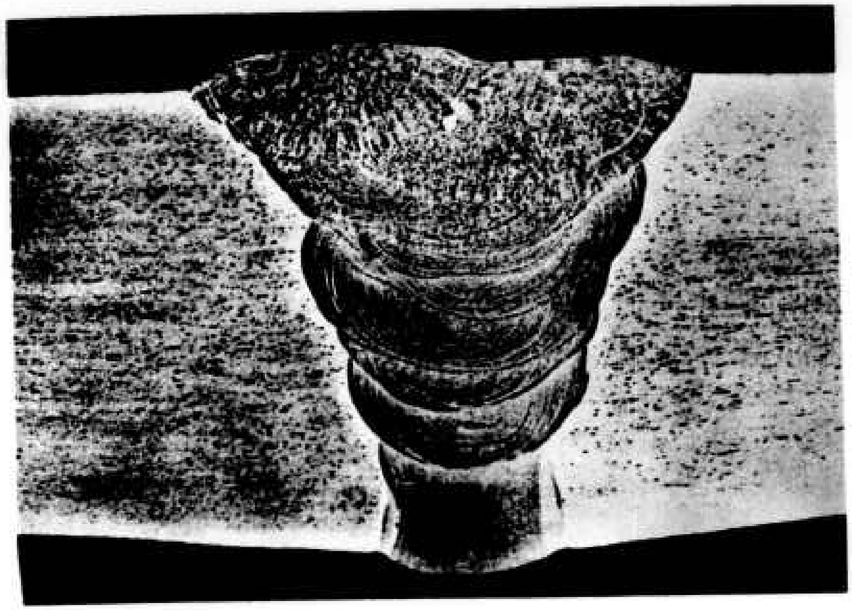
Parent Metal (1000X)



H. A. Zone (1000X)

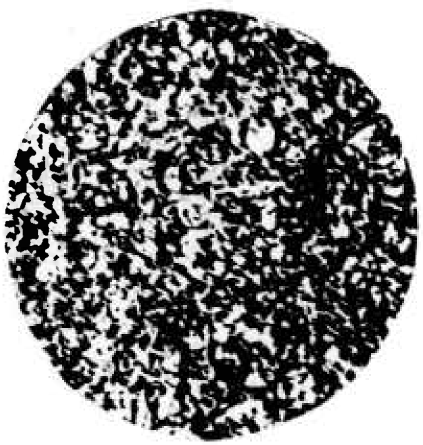
Weld Zone (1000X)

Figure 37. Metallographic Study of AMS 6434 Weldment - Quenched and Tempered at 800F - 2 hrs.



Weld Macrograph (5X)

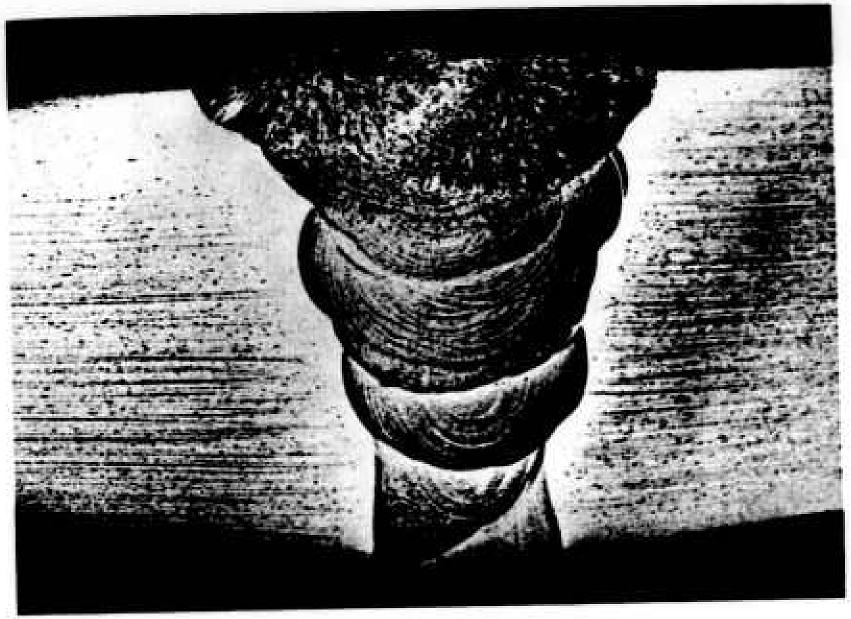
Parent Metal (1000X)



H. A. Zone (1000X)

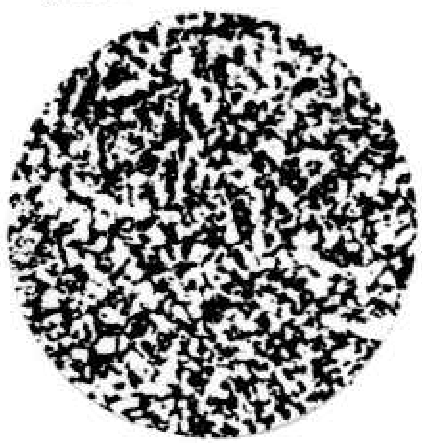
Weld Zone (1000X)

Figure 38. Metallographic Study of AMS 6434 Weldment - Quenched and Tempered at 900F - 2 hrs.



Weld Macrograph (5X)

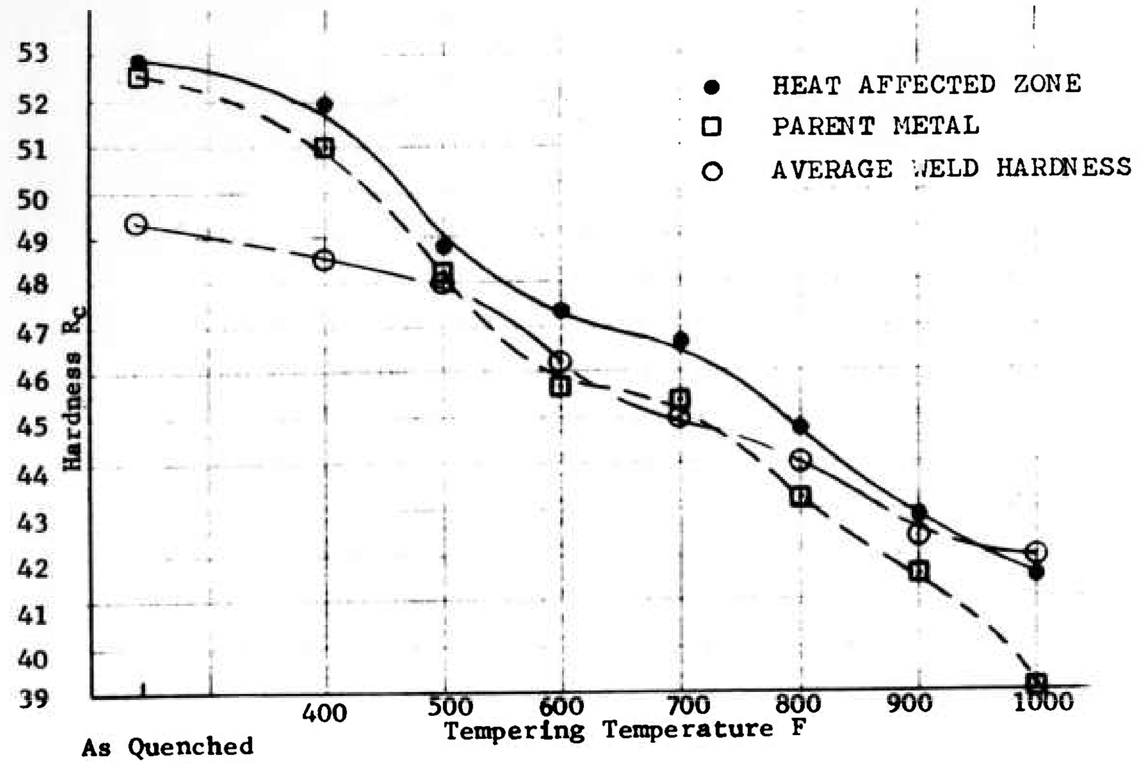
Parent Metal (1000X)



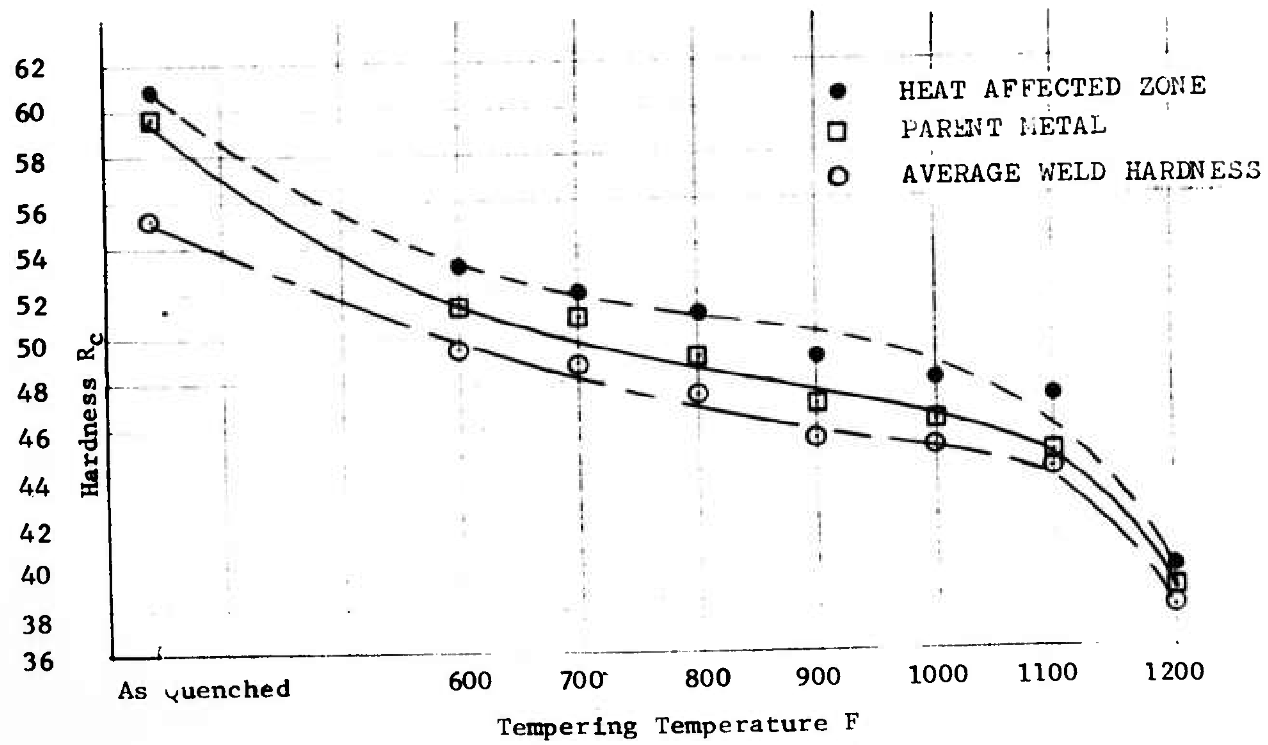
H. A. Zone (1000X)

Weld Zone (1000X)

Figure 39. Metallographic Study of AMS 6434 Weldment - Quenched and Tempered at 1000F - 2 hrs.

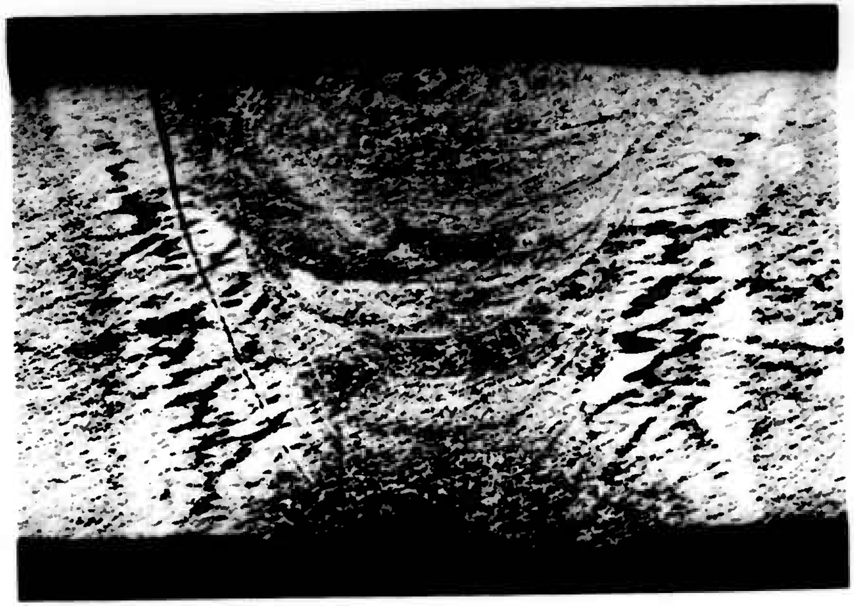


(a) AMS 6434 Austenitized 1600F



(b) D-6-AC Austenitized 1625F

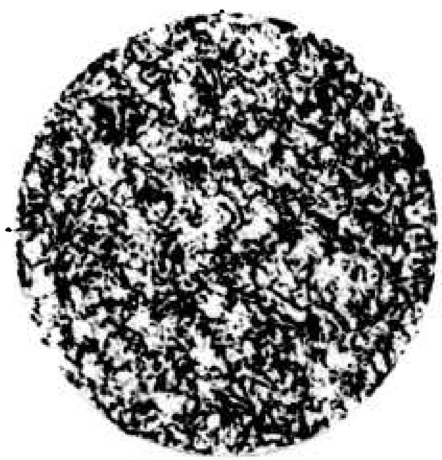
Figure 40. A hardness survey on plate weldments of AMS 6434 and D-6-AC (Parent metal filler wire)



Weld Macrograph (6X)

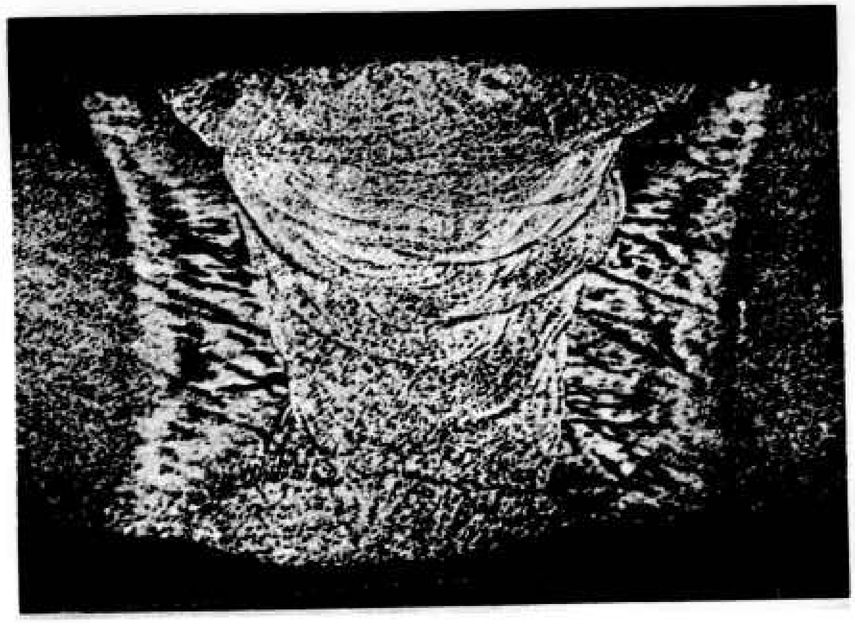
Parent Metal (1000X)

H. A. Zone (1000X)



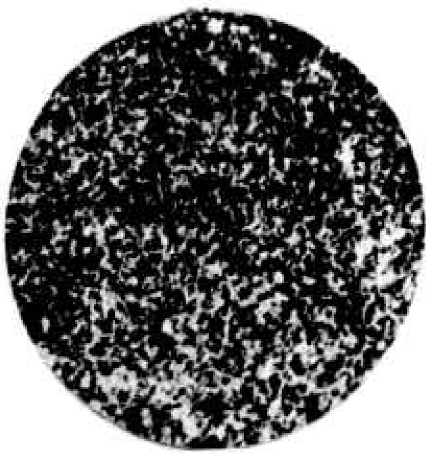
Weld Zone (1000X)

Figure 41. Metallographic Study of D-6-AC Weldment - As-Quenched from 1625F



Weld Macrograph (6X)

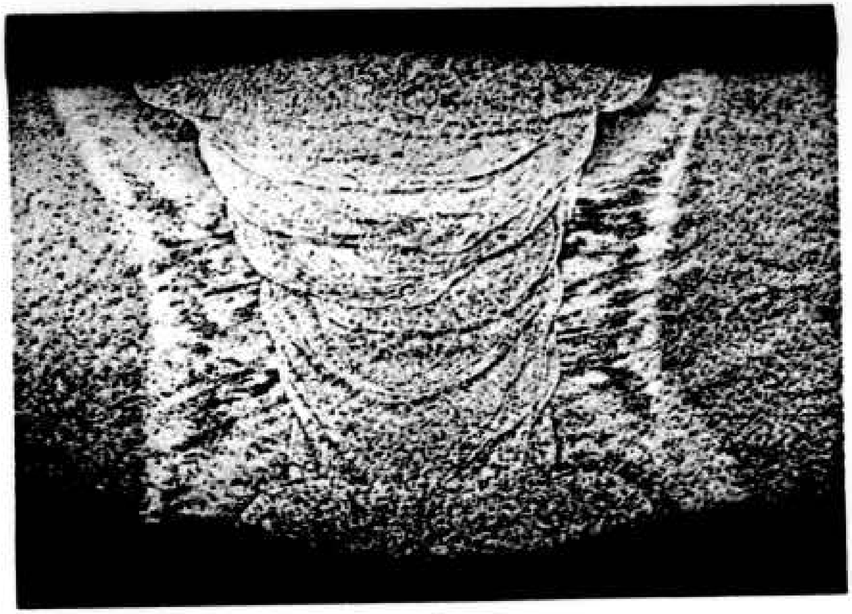
Parent Metal (1000X)



H. A. Zone (1000X)

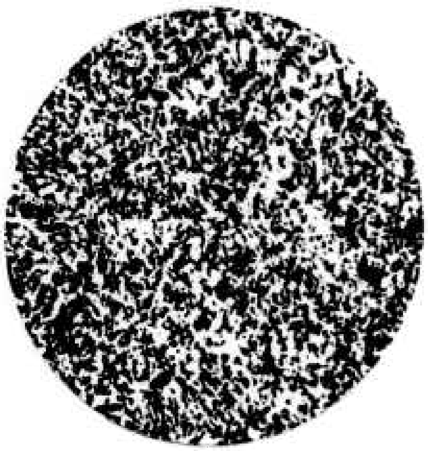
Weld Zone (1000X)

Figure 42. Metallographic Study of D-6-AC Weldment - Quenched and Tempered at 600F - 2 hrs.

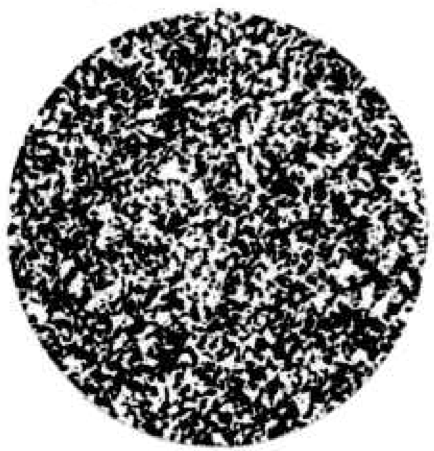


Weld Macrograph (6X)

Parent Metal (1000X)



H. A. Zone (1000X)



Weld Zone (1000X)

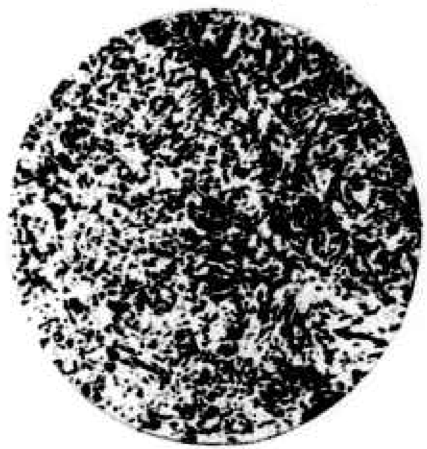
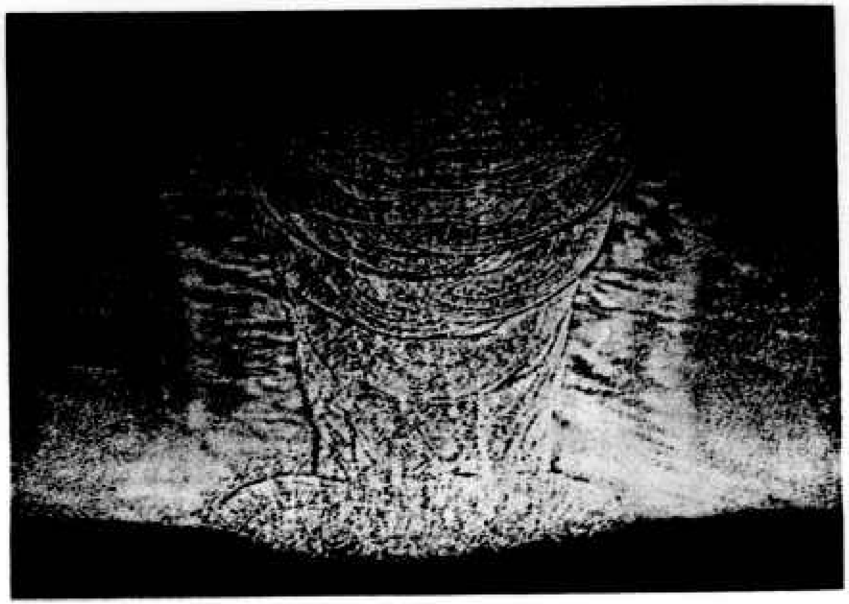


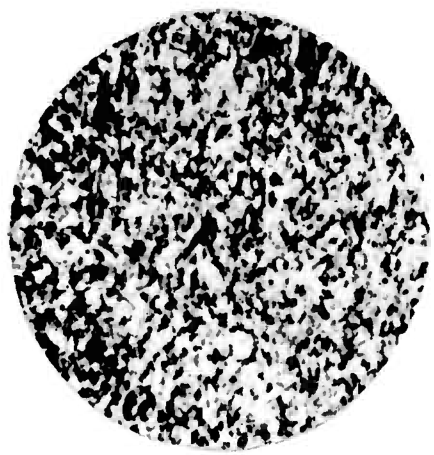
Figure 43. Metallographic Study of D-6-AC Weldment - Quenched and Tempered at 700F - 2 hrs.



Weld Macrograph (6X)

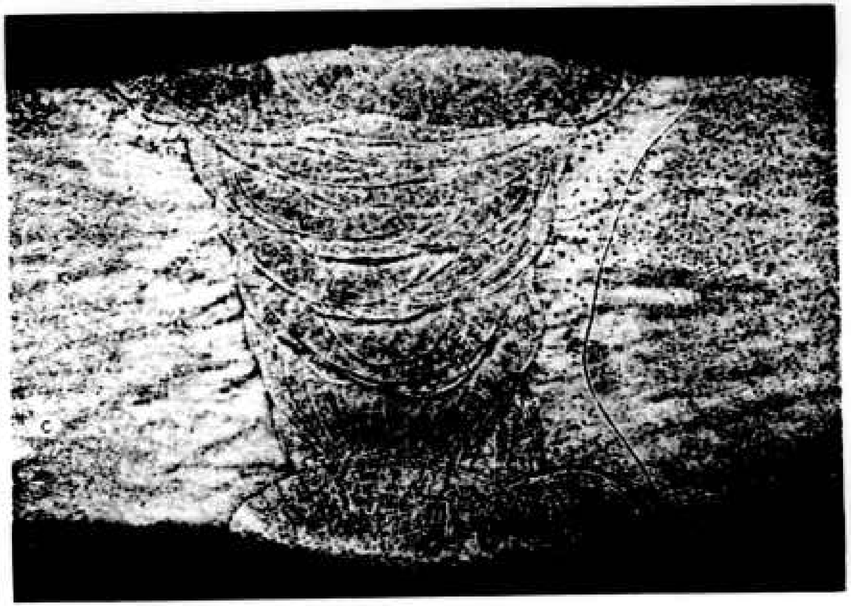
Parent Metal (1000X)

H. A. Zone (1000X)



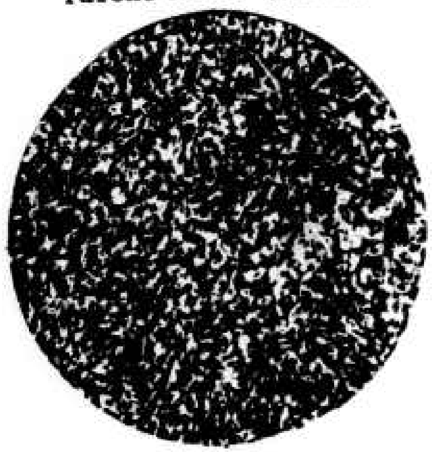
Weld Zone (1000X)

Figure 44. Metallographic Study of D-6-AC Weldment - Quenched and Tempered at 800F - 2 hrs.

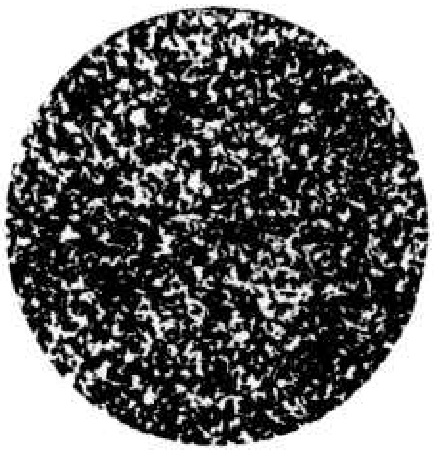


Weld Macrograph (6X)

Parent Metal (1000X)

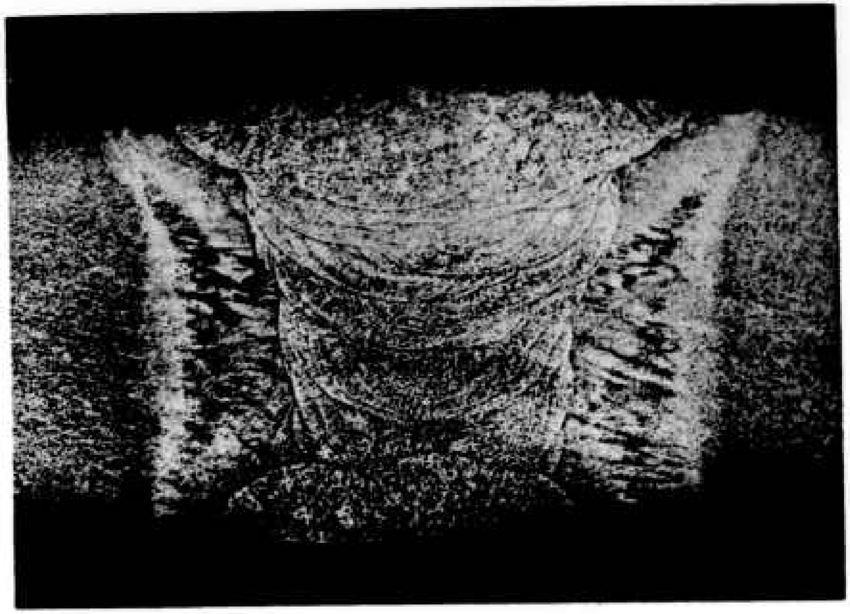


H. A. Zone (1000X)



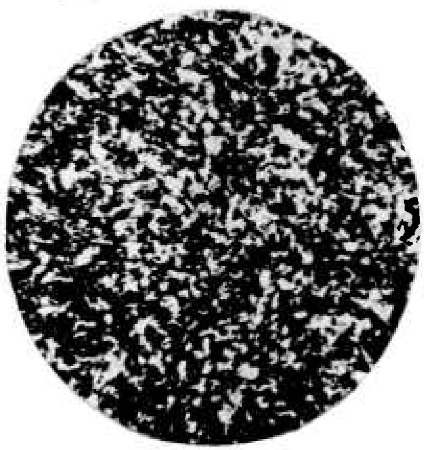
Weld Zone (1000X)

Figure 45. Metallographic Study of D-6-AC Weldment - Quenched and Tempered at 900F - 2 hrs.



Weld Macrograph (6X)

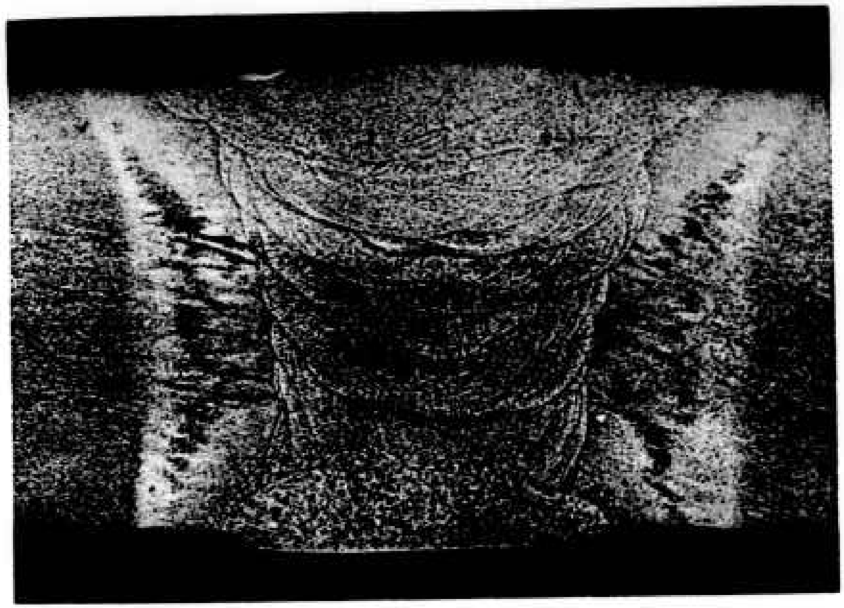
Parent Metal (1000X)



H. A. Zone (1000X)

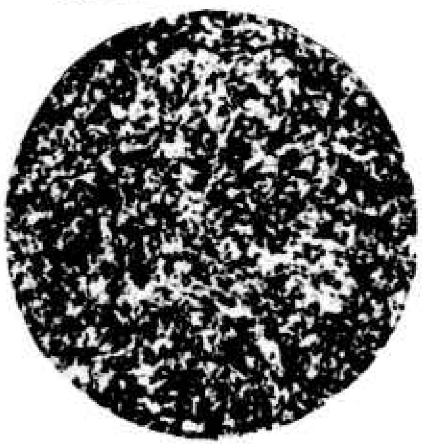
Weld Zone (1000X)

Figure 46. Metallographic Study of D-6-AC Weldment - Quenched and Tempered at 1000F - 2 hrs.

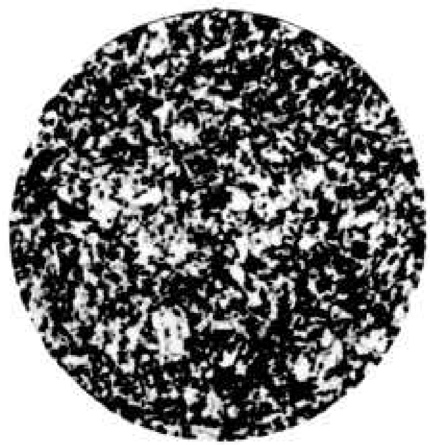


Weld Macrograph (6X)

Parent Metal (1000X)



H. A. Zone (1000X)



Weld Zone (1000X)

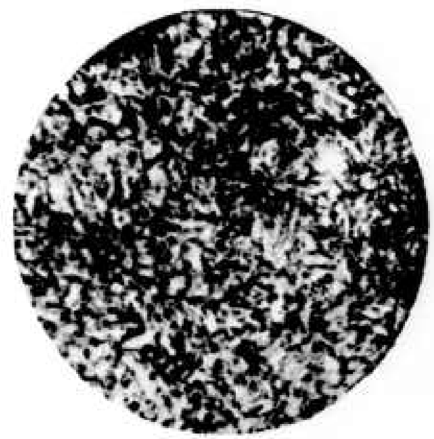
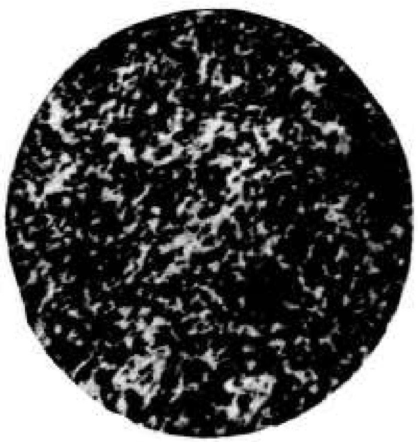


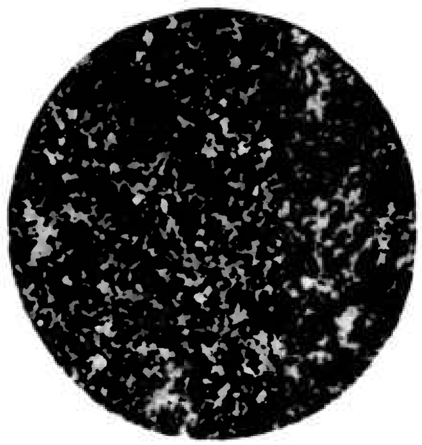
Figure 47. Metallographic Study of D-6-AC Weldment - Quenched and Tempered at 1100F - 2 hrs.

Weld Macrograph (6X)

Parent Metal (1000X)



H.A. Zone (1000X)



Weld Zone (1000X)

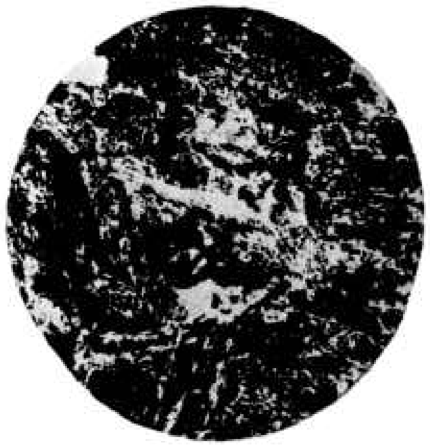
Figure 48. Metallographic Study of D-6-AC Weldments Quenched and Tempered at 1200F - 2 hrs.

Weld Macrograph (4X)

Composite Weld (60X)

Parent Metal (1000X)

H. A. Zone (1000X)



Weld Zone (1000X)

Figure 49. Metallographic Study of 200 KSI Maraging 18 Per Cent Nickel Steel Weldments - As Welded Condition

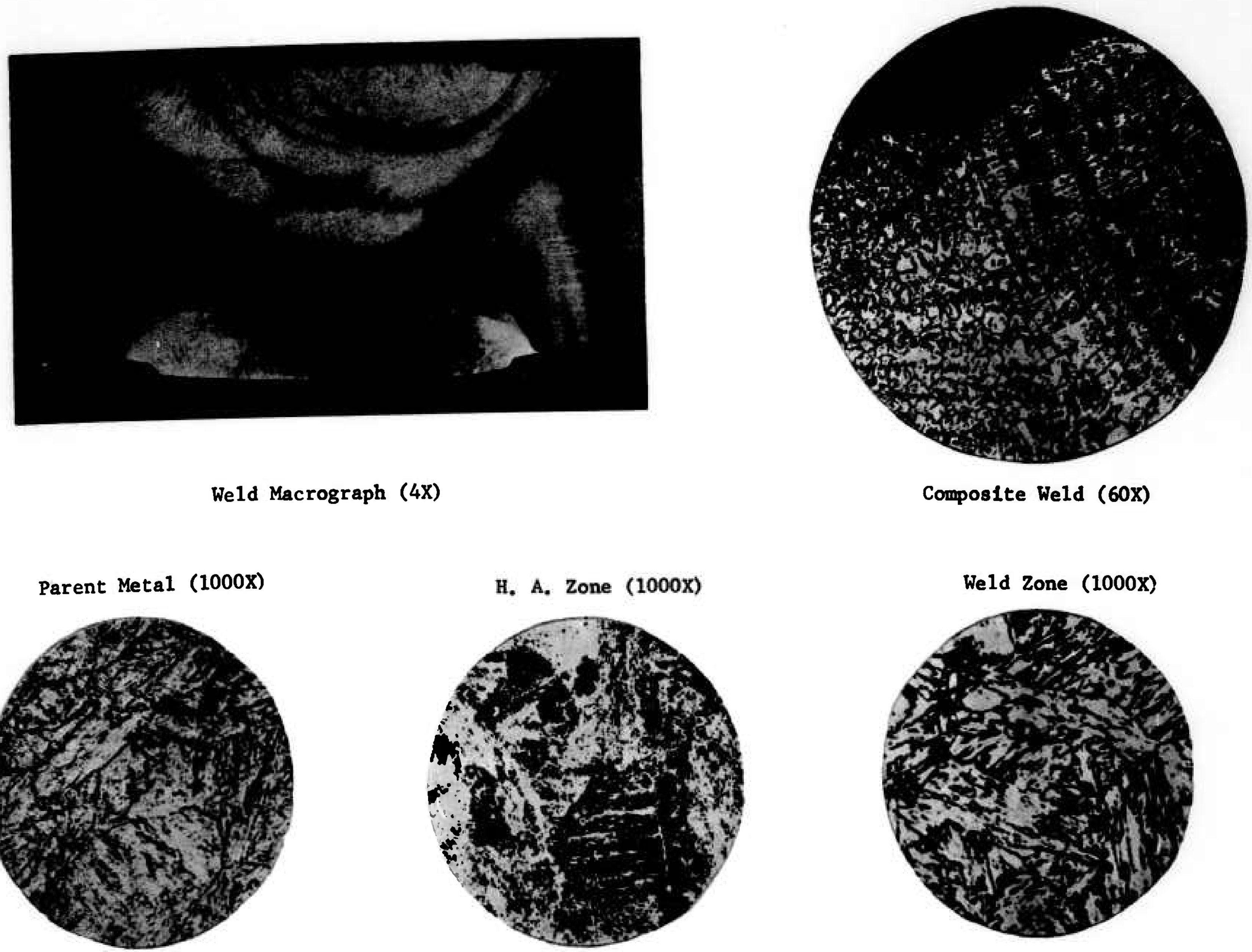
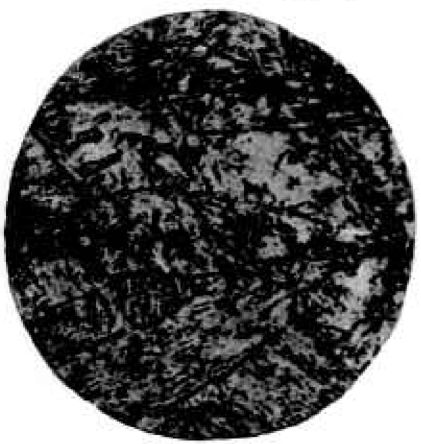


Figure 50. Metallographic Study of 200 KSI Maraging 18 Per Cent Nickel Steel Weldments - Aged 3 hrs. at 850F

Weld Macrograph (4X)

Composite Weld (60X)

Parent Metal (1000X)



H. A. Zone (1000X)

Weld Zone (1000X)

Figure 51. Metallographic Study of 200 KSI Maraging 18 Per Cent Nickel Steel Weldments - Aged 3 hrs. at 900F

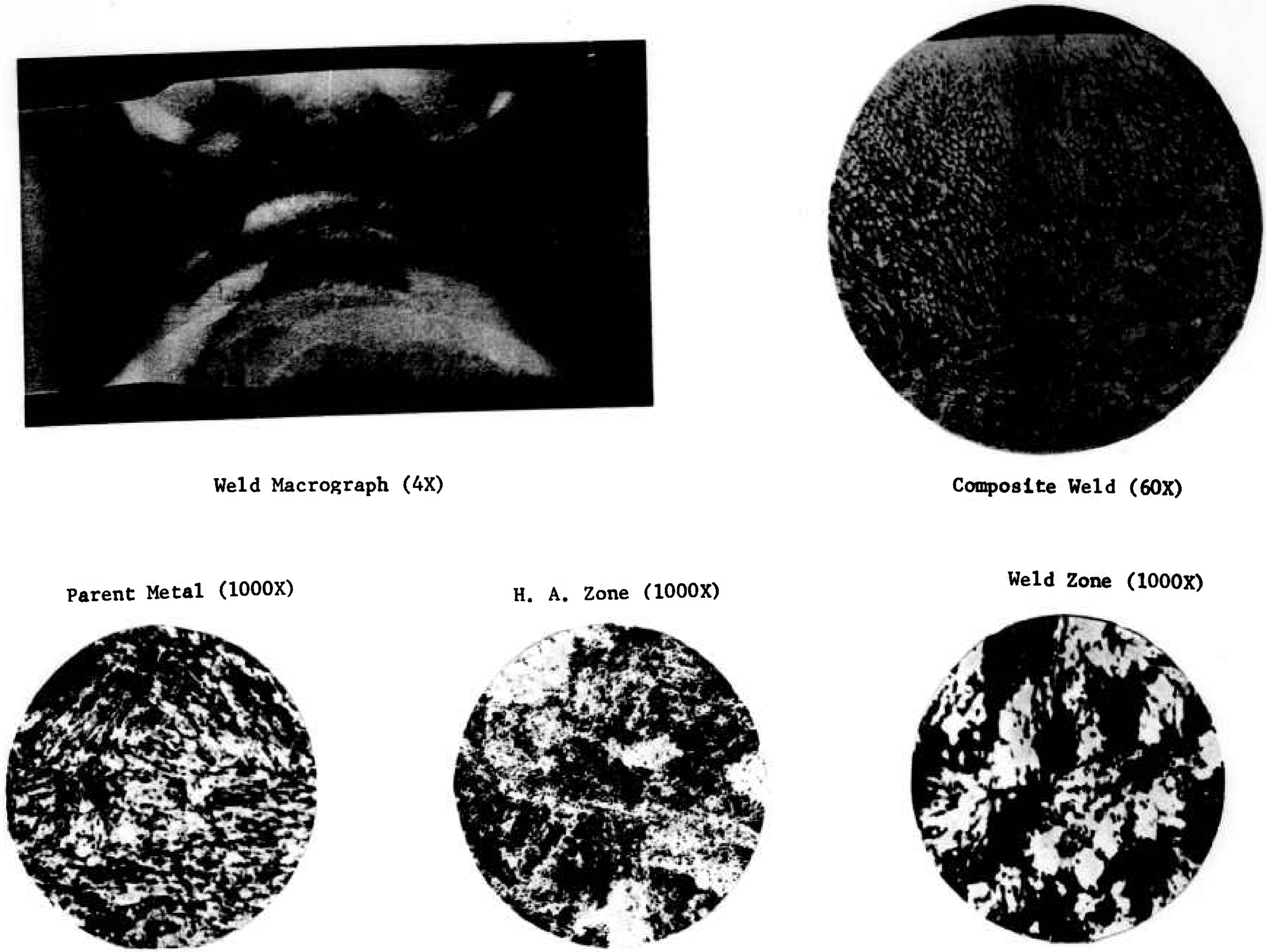


Figure 52. Metallographic Study of 200 KSI Maraging 18 Per Cent Nickel Steel Weldments - Aged 3 hrs. at 950F

Weld Macrograph (4X)

Composite Weld (60X)

Parent Metal (1000X)

H. A. Zone (1000X)

Weld Zone (1000X)

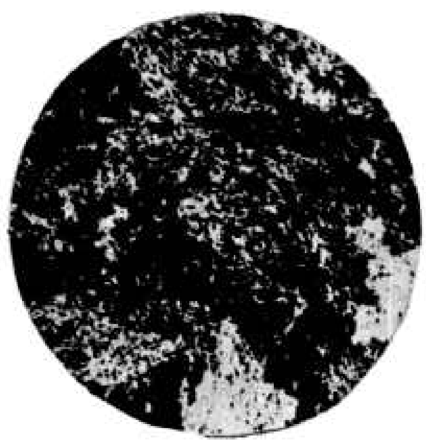
Figure 53. Metallographic Study of 200 KSI Maraging 18 Per Cent Nickel Steel Weldments - Aged 3 hrs. at 1000F

Weld Macrograph (4X)

Composite Weld (60X)

Parent Metal (1000X)

H. A. Zone (1000X)



Weld Zone (1000X)

Figure 54. Metallographic Study of 200 KSI Maraging 18 Per Cent Nickel Steel Weldments - Aged 3 hrs. at 1050F

Weld Macrograph (4X)

Composite Weld (60X)

Parent Metal (1000X)

H. A. Zone (1000X)

Weld Zone (1000X)

Figure 55. Metallographic Study of 200 KSI Maraging 18 Per Cent Nickel Steel Weldments - Aged 3 hrs. at 1100F

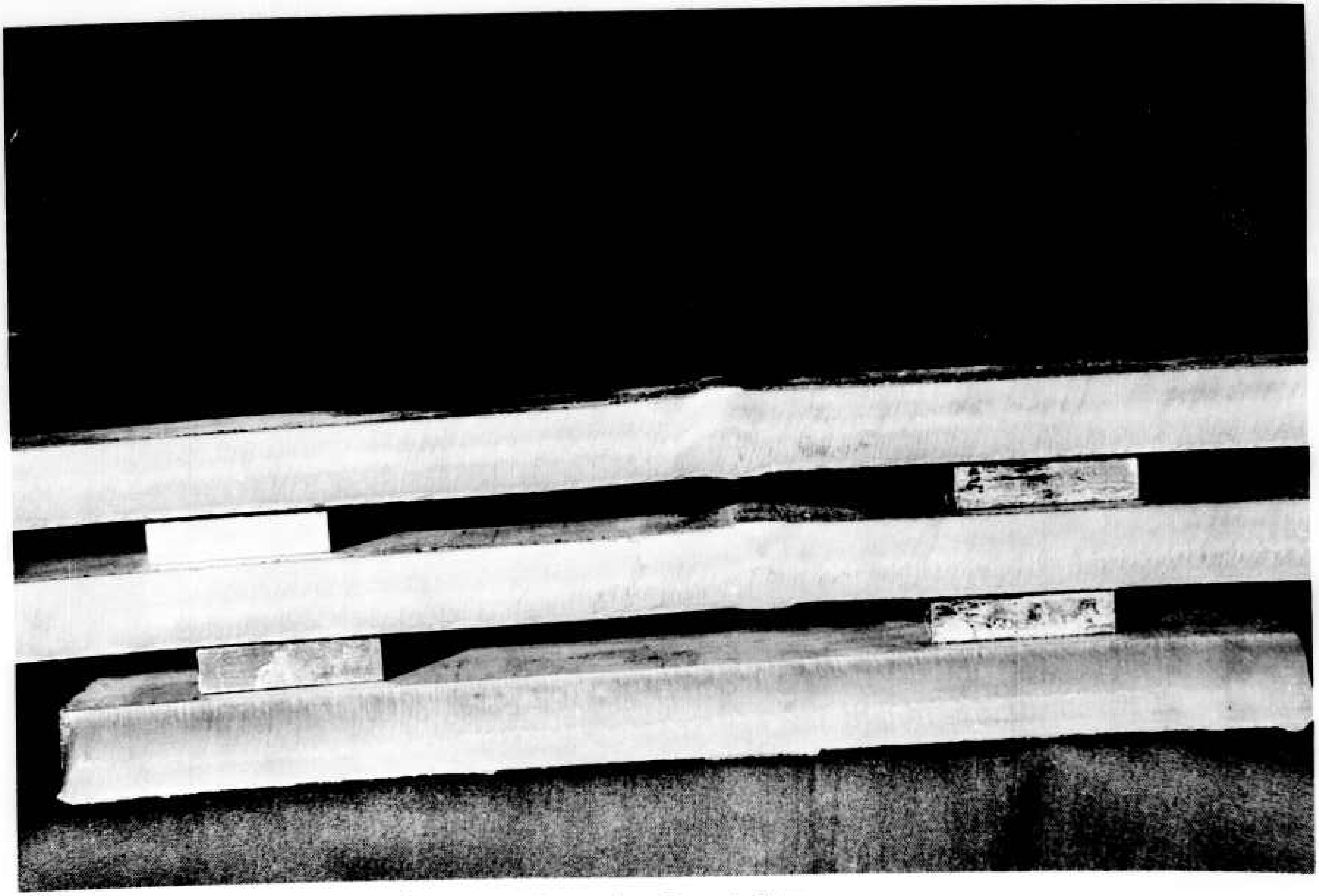


Figure 56. Plasma Arc Burned Edges
Maraging 18% Ni. 250 Ksi annealed 1/2" Tk.

MARAGING STEEL

TABLE XXI

Bethlehem Heat # 120-D-163

1/2 in. thick plate

Parent material

T. S. - 270,000 psi

Y. S. - 254,000 psi

Weld bevel was prepared by plasma arc burning the annealed plate. Burned area was wire brushed to remove loose scale. Weld applied using TIG method. Test bars were aged at 920° F for 3 hours.

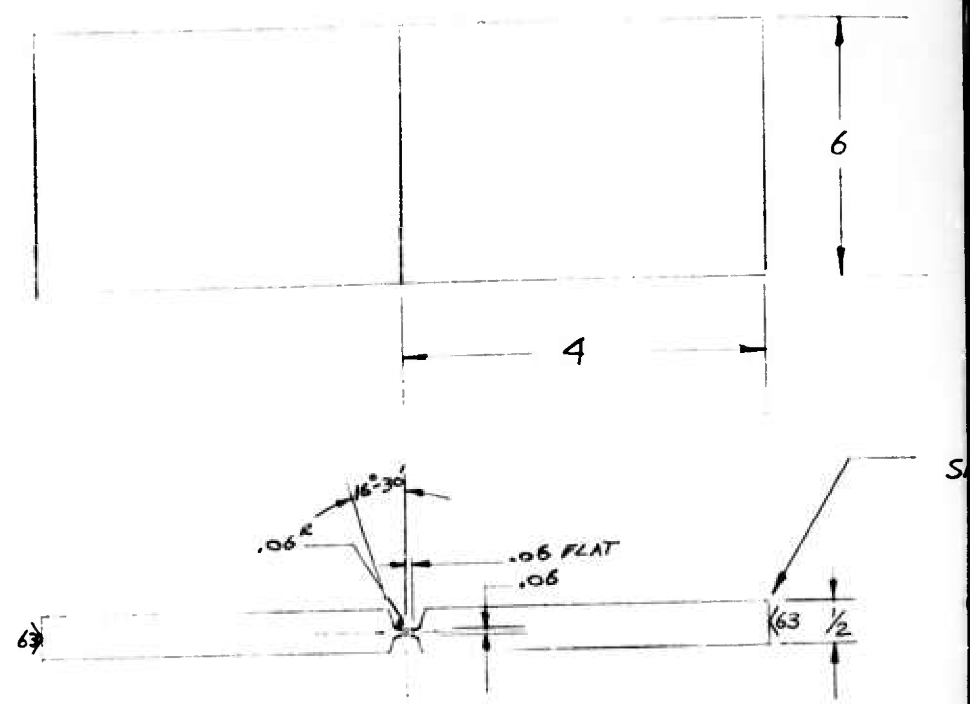
	1	2	3	4
Y. S.	248	248	250	244
T. S.	255	255	260	255
F. S.	295	272	275	285
% Red.	26.2	11.8	7.9	18.8
% Elong. 1 in.	14	9	5*	11
% Elong. 2 in.	7	4	3 1/2	5 1/2

*Parent metal break on 1 in. gage line

Weld eff. based on T. S. - 95%

based on Y. S. - 98%

1



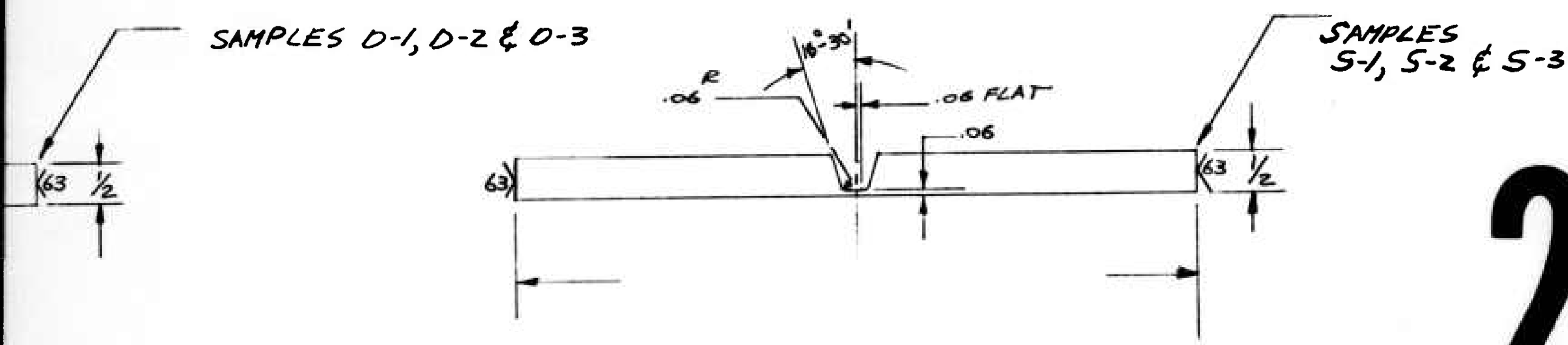
IDENT.	1 UN-WELDED LENGTH	2 WELDED LENGTH	DIFFERANCE OF 1 & 2	R/C	
D-1	8.024-8.027-8.028	7.993-7.980-7.970	.031-.047-.058	32	7.9
D-2	8.017-8.014-8.011	7.965-7.952-7.932	.052-.062-.079		7.9
D-3	8.020-8.023-8.024	7.978-7.976-7.962	.042-.047-.062		7.9
S-1	8.037-8.037-8.035	7.978-7.959-7.937	.059-.078-.098		7.9
S-2	8.039-8.042-8.044	7.981-7.969-7.957	.058-.073-.087		7.9
S-3	8.036-8.039-8.040	7.979-7.972-7.964	.057-.067-.076		7.9

BILL OF MATERIAL				
ITEM	DESCRIPTION	STOCK SIZE	MATERIAL	REQ'D

6

U.S. STEEL MARAGING

HEAT Nº X-13371



2

NCE	R/C	3 LENGTH AFTER REPAIRS	DIFFERANCE OF 2 & 3	4 AGED LENGTH	DIFFERANGE OF 3 & 4	R/C
58	32	7.982-7.970-7.963	.011-.010-.007	7.979-7.969-7.960	.003-.001-.003	50
79		7.954-7.944-7.937	.011-.008-.005	7.950-7.940-7.929	.004-.004-.008	
62		7.969-7.962-7.956	.009-.014-.006			
98		7.977-7.958-7.936	.001-.001-.001			
87		7.982-7.968-7.955	.001-.001-.002	7.977-7.963-7.951	.005-.005-.004	
76		7.978-7.969-7.964	.001-.003-.000	7.973-7.967-7.960	.005-.003-.004	

CHANGE

ITEM

EXCELCO DEVELOPMENTS INC.

SILVER CREEK, N. Y.

TITLE WELD SHRINKAGE DATA

DFTM. RSM	DATE 10-25-62	E — SK-10-25-62-1
CHKD.	SCALE N.T.S.	
APPD.	JOB	

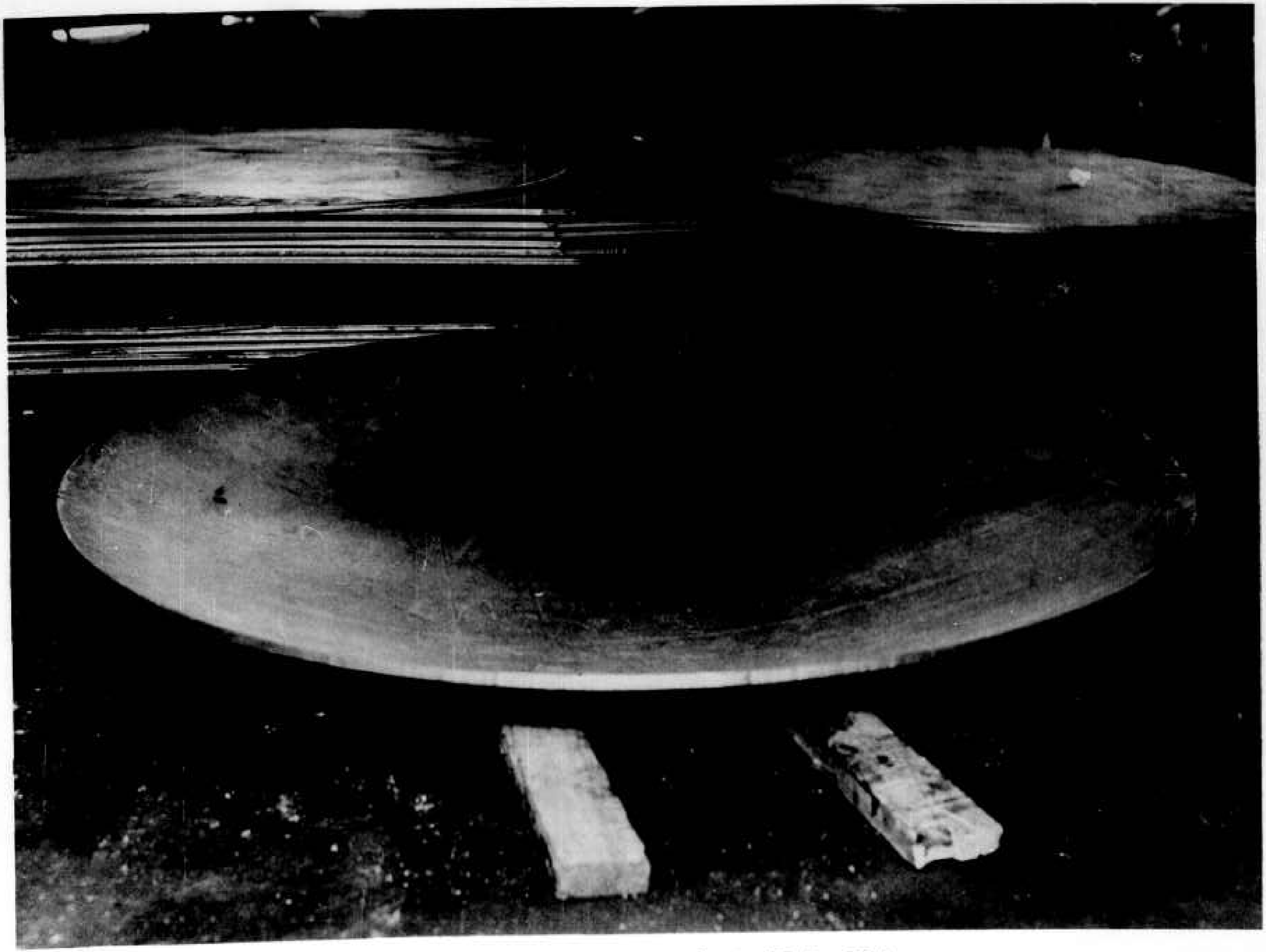
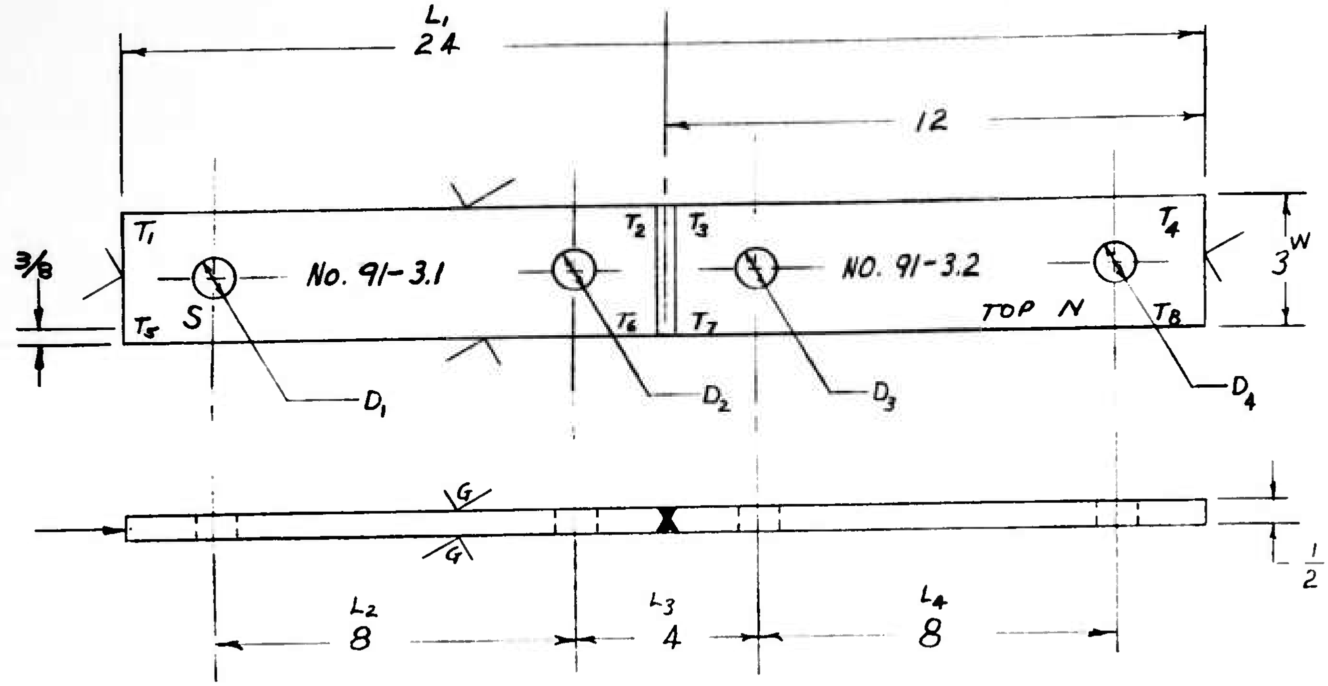


Figure 59 120 in. Dia. Hemispherical Dollar Plate
Maraging 18% Ni. 250 Ksi annealed 1/2" Tk.

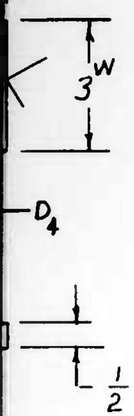


1

MATERIAL : MARAGING STEEL
LUKENS HEAT NO. 4780-70979

NOTE :
SHRINKAGE IN 23.2218 LENGTH IS .000378 IN/IN

CONDITION	FLATNESS	HOLE DIA'S				LENGTHS				THICKNESS							
		D_1	D_2	D_3	D_4	L_1	L_2	L_3	L_4	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
AS WELDED	.001	1.000	1.001	1.001	1.001	23.2130	8.000	4.002	8.000	.460	.4605	.4605	.461	.460	.4605	.4605	.461
AGED	.004	1.000	1.001	1.001	1.001	23.2218	7.996	4.000	7.996	.4595	.4603	.4605	.4609	.4596	.4605	.4603	.4607



BILL OF MATERIAL				
ITEM	DESCRIPTION	STOCK SIZE	MATERIAL	REQ'D

2

PROCEDURE:

1. PREPARE SAMPLES FOR WELDING.
2. WELD
3. MACHINE ALL OVER
4. GRIND FLAT AND PARALLEL $\sqrt{16}$
5. JIG BORE 4 HOLES - 1" DIA.
6. MEASURE AND RECORD DATA FOR "AS WELDED"
7. MARAGE AT 900°F $^{+25}_{-0}$ 3 HOURS
8. MEASURE AND RECORD DATA FOR "AGED"

MEASURING INSTRUMENTS
1. GRANITE SURFACE PLATE #A4254
2. FEDERAL ELECTRIC GAGE #230P-50
3. 0-1 IN MICROMETER (.0001 IN INCREMENT) #T230F
4. 3-4 IN MICROMETER (.0001 IN INCREMENT) #226
5. 12 IN VERMIER #123

S				WIDTH	R_C
T_5	T_6	T_7	T_8	W	
.460	.4605	.4605	.461	3.0395 3.039 3.039 3.0385	29/30
.4596	.4605	.4603	.4607	3.0389 3.0383 3.0382 3.0375	43/44

CHANGE	EXCELCO DEVELOPMENTS INC. SILVER CREEK, N. Y.		
	TITLE WELD SHRINKAGE DATA.		
	DFTM. EVB	DATE 10/8/62	E-SK-10-2-62-1
ITEM	CHKD.	SCALE	
	APPD.	JOB	

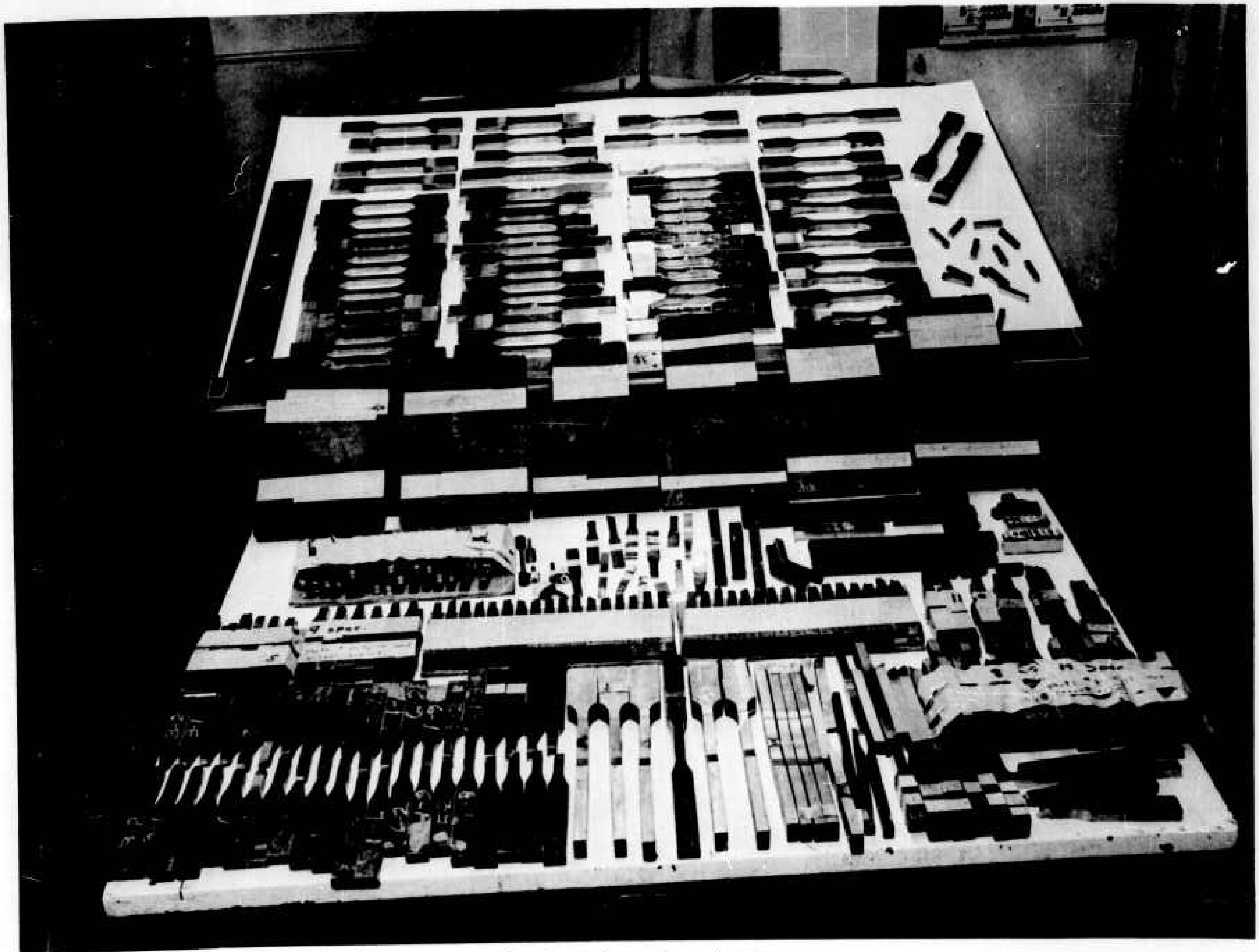


Figure 61. Typical Test Specimens
Plate & Forging Material on Metal Test Program

E-3291-1
15 Jan 1963

MATERIAL DESCRIPTION AND SPECIFICATION (TENTATIVE)

STEEL, 18% Ni. Maraging Steel 250 Ksi Level

1. SCOPE

1.1 This specification covers premium aircraft quality 18% Ni Maraging steel. Specific guaranteed chemistry and mechanical properties are required.

1.2 Material forms covered are sheet plate, bar, and forgings to be used in rocket engine cases.

2. APPLICABLE DOCUMENTS

2.1 The following Government documents of issues in effect on date of order form a part of this specification:

2.1.1	Federal Test Method Standard No. 151	Metals, Test Methods
2.1.2	Federal Std No. 183	Continuous Identification Markings of Iron and Steel Products

2.2 The following Non-Government documents of issues in effect on date of order form a part of this specification:

2.2.1	AMS-2252A	Tolerances - Alloy Steel Plates
2.2.2	ASTM E 45	Recommended Practice for Determining the Inclusion Content of Steel
2.2.3	ASTM E 112-61	Estimating the Average Grain Size of Metals

3. REQUIREMENTS

3.1 The steel supplied to this specification shall be manufactured by the air melt or air melt vacuum degassed process.

3.2 The steel shall be supplied in the mill annealed condition. Specifically the material shall be heated to 1500° F +25 - 0 held for 1 hour per inch of thickness minimum and air cooled. The hardness range shall be 34 R_C maximum.

E-3291-1
15 Jan 1963

MATERIAL DESCRIPTION AND SPECIFICATION
(TENTATIVE)

3. REQUIREMENTS (CONT'D)

3.3 The ladel chemistry shall meet the following composition and the aim shall be for a check chemistry to meet the following:

	Check & Ladel Min.	Check Max.	Ladel Max.
Carbon	---	.03	.03
Manganese	---	.10	.10
Silicon	---	.10	.10
Sulphur	---	.01*	.01
Phosphorus	---	.01*	.01
Nickel	17.5	19.0	19.0
Molybdenum	4.6	5.2	5.2
Cobalt	7.0	8.5	8.5
Titanium	.40	.55	.60
Aluminum	.05	.15	.15
Boron			.003
Zirconium			.02
Calcium			.05

*The combination of Sulphur and Phosphorus should not exceed .014.

3.4 When aged at 915° F ± 10° F for 3 to 4 hours, the unixial tensile properties shall meet the following minimums:

Yield strength (.2% offset)	235,000 psi
Tensile strength	245,000 psi
Elongation (2 in. gage)	5 per cent
Reduction of area	30 per cent

3.5 The inclusion rating shall be based on the worst area of inclusion found in the samples examined. The values required may be negotiated at the time of ordering. Desirable limits are as follows:

Inclusion type	Thin	Heavy
A	1 1/2	1
B	1 1/2	1
C	1 1/2	1
D	2	1 1/2

3.6 The grain size shall be 5 or finer.

E-3291-1
15 Jan 1963

MATERIAL DESCRIPTION AND SPECIFICATIONS (TENTATIVE)

4. QUALITY ASSURANCE

4.1 The manufacturer shall make every effort to produce a uniform sound material free of surface blemishes and internal faults.

4.2 Ultrasonic inspection of all material is required. Inspection may be made on the slab only in the case of rolled material. Forgings will be inspected in the rough machined condition.

4.3 Sampling will be made as follows:

4.3.1 Chemistry - Each heat ot each mill slab if more than one per heat.

4.3.2 Mechanical Properties - Two samples each direction from each plate.
Note less than three samples from each heat from which forgings are made.

4.3.3 Grain Size - Two samples from each heat.

4.3.4 Inclusion Count - One sample from each heat.

4.3.5 Ultrasonic inspection as required in 4.2.

4.3.6 Visual, X-ray and magnetic particle inspection are tools of the manufacturer and are to be used at his discretion.

4.4 The manufacturer shall furnish not less than three certified copies of the test results on chemistry, mechanical properties, R_c hardness of annealed material, grain size, inclusion count and ultra sonic inspection.

5. GENERAL PROVISIONS

5.1 Continuous marking with a suitable ink is desired. Marking the identification in several locations on each piece will be acceptable.

5.2 Plate shall be finished by mechanically descaling and lightly oiling. Forgings shall be rough machined and lightly oiled.

Prepared by:

EXCELCO DEVELOPMENTS, INC.

W. Abbott

D. Newell

E-3291-2
15 Jan 1963

MATERIAL DESCRIPTION AND SPECIFICATION (TENTATIVE)

WELD WIRE, 18% Ni. Maraging Steel Vacuum Melted 250 Ksi Level

1. SCOPE

1.1 This specification covers premium quality 18% Ni. Maraging Steel Weld Wire for use in rocket engine cases.

1.2 The material used is limited to that manufactured by the vacuum arc remelt process.

2. FORM

2.1 Wire will be supplied as round drawn wire. Diameter of wire and spool size to be specified when ordering.

3. REQUIREMENTS

3.1 Use only vacuum arc remelt material.

3.2 The chemistry shall meet the following composition:

	Min.	Max.
Carbon	---	.02
Manganese	---	.10 (.05 desirable)
Silicon	---	.10
Sulphur	---	.005
Phosphorus	---	.005
Nickel	17.5	18.5
Molybdenum	4.4	4.8
Cobalt	7.5	8.5
Titanium	.40	.50
Aluminum	.07	.15

3.3 The wire shall be spooled and each spool individually packed in a container that has been purged with argon before sealing.

3.4 Each container shall be identified as to type of material, wire diameter, net weight, heat number and purchase order number.

3.5 At least three certified copies of the chemistry shall be furnished with each order.

E-3291-2
15 Jan 1963

MATERIAL DESCRIPTION AND SPECIFICATION
(TENTATIVE)

4. GENERAL PROVISIONS

4.1 The manufacturer shall to the best of his ability provide wire that is uniform in size and quality.

4.2 It is the manufacturers responsibility to visually examine the wire at the time of packaging to assure cleanliness and a surface free of flaws and rust.

Prepared by:

EXCELCO DEVELOPMENTS, INC.

W. ABBOTT

D. NEWELL

Rocket Research Laboratories,
Edwards Air Force Base,
California
Report No.

Investigations and Evaluation of High Strength Steel in Heavy Gauges for Large Diameter Solid Propellant Rocket Engine Cases. Final Report 28 February 1963 104 p. including illustrations, tables, photographs,
Research program on large alloy high strength steels for large solid propellant rocket engine

1. AMS 6434
2. D6AC
3. Maraging 18% Nickel

I. Contract 04(611)8517
II. Excelco Dev. Inc. Silver Creek, N. Y.
III. Mellon Inst. Pittsburgh, Penn.
IV. W. D. Abbott
V. Dr. G. K. Bhat

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